U K A F

INDUSTRIES INC.

UKAF
INDUSTRIES INC.
829 FIRST STREET WEST
NORTH VANCOUVER, B.C.
V7P 1A4
(604) 980-8063

UKAF File No. 27629

Project Report

DEVELOPMENT OF A SIMPLE FLOW TEST APPARATUS FOR BIOMASS MATERIALS

Prepared for:

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Energy, Mines and Resources Canada
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Contractor:

UKAF Industries Inc.
829 First Street West
North Vancouver, B.C.
V7P 1A4

Tel. (604) 980-6063

Major Sub-Contractor:

B.C. Research
3650 Wesbrook Mall
Vancouver, B.C.
V6S 2L2

Tel. (604) 224-4331

Principal Investigators:

Mr. Dave Skeath, President, UKAF Industries Inc.
Mr. Nazmir Bundalli, Program Leader, B.C. Research

Scientific Authority:

Ms. Cecille Granger
Renewal Energy Division
Energy, Mines and Resources Canada
460 O'Connor Street
Ottawa, Ontario
K1A 0E4

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SUMMARY

A simple tester capable of assessing the flow characteristics of biomass materials was designed and constructed. The tester essentially consists of an acrylic box with a deck at the bottom that opens out to form a slot running the width of the box. An important feature of the tester is that the widening of the slot occurs without disturbing the material in the box that is being tested. As the slot is widened, at some point the material above it cannot support itself and collapses to form a "rat-hole". The width of the slot is related to the flowability of the material being tested - i.e., the larger the slot width required to form a rat-hole, the poorer the flow characteristics of the material.

Tests were done on a range of biomass materials using the new tester. Tests on the same materials were also done on the ring shear cell, using the procedures developed at B.C. Research (1). Comparison of the slot width on the new tester required to form a rat-hole, to the calculated outlet width of a mass flow hopper to avoid bridging of material at the bin outlet, showed good correlation. Scatter in the results was in the acceptable range and was attributed to inaccuracies of both the test methods.

The UKAF tester provides a simple, quick and an inexpensive method of assessing the flow characteristics of biomass materials. The results from the tester can be used for estimating critical bin design parameters to avoid flow problems, as well as comparing different biomass materials for flow. The following guidelines are recommended for using the results of the tester to characterize biomass materials as well as to select the mass flow bin outlet width for reliable flow:

Slot Width on UKAF Tester cm	Flowability	Recommended Mass Flow Outlet Width m
<10	Very Free	0.30 - 0.40
10 - 15	Free Flowing	0.35 - 0.60
15 - 20	"Normal"	0.60 - 1.00
20 - 25	Difficult	1.00 - 1.25
>25	Very Difficult	>1.30

The tester as designed worked well. Constructional details and operating procedure are provided in this report.

RÉSUMÉ

On a conçu et fabriqué un simple appareil d'essai capable d'évaluer les caractéristiques d'écoulement de diverses matières de la biomasse. L'appareil est constitué essentiellement d'une boîte en acrylique dont le fond s'ouvre en une fente sur la largeur de la boîte. Une particularité importante de l'appareil est qu'on peut faire varier l'ouverture de la fente sans déranger le contenu de la boîte. La fente est élargie jusqu'au point où les matières contenues dans la boîte s'effondrent pour former une sorte de poche d'air ou "trou de cheminée". La largeur de la fente est mise en rapport avec les caractéristiques d'écoulement des matières qui font l'objet de l'essai, c'est-à-dire que plus il faut élargir la fente pour que les matières s'effrondrent, moins bonnes sont les caractéristiques d'écoulement de ces matières.

Le nouvel appareil a servi à l'essai d'une gamme de matières organiques. Certaines matières ont aussi été soumises à l'essai de la cellule annulaire à effet de cisaillement, selon la méthode mise au point au laboratoire B.C. Research (1). On a établi une bonne corrélation entre la largeur de la fente du nouvel appareil qui est nécessaire pour qu'il se crée un trou de cheminée et la largeur calculée de l'ouverture d'un trémie à débit massique qui est nécessaire pour éviter le pontage du contenu à l'ouverture du silo. La dispersion des résultats, acceptable, a été attribuée aux inexactitudes des deux méthodes d'essai.

L'apparaeil UKAF fournit un moyen simple, rapide et peu coûteux d'évaluer les caractéristiques d'écoulement des matières organiques qui composent la biomasse. Les résultats obtenus au moyen de cet appareil peuvent servir à évaluer les paramètres critiques de conception du silo de façon à éviter les difficultés d'écoulement ainsi qu'à comparer les caractéristiques d'écoulement de diverses matières. Les données suivantes aideront à déterminer les caractéristiques d'écoulement et à choisir la largeur de l'ouverture du silo de débit massique :

Largeur de la Fente de l'Appareil d'Essai UKAF en cm	Écoulement	Largeur d'Ouverture Recommandée du Silo en m
<10	très libre	0.30 - 0.40
10 - 15	libre	0.35 - 0.60
15 - 20	"normal"	0.60 - 1.00
20 - 25	difficile	1.00 - 1.25
>25	très difficile	>1.30

L'appareil fonctionne bien. Les détails de fabrication et de fonctionnement sont donnés dans le rapport.

BACKGROUND

Lack of test equipment and methods to characterize the flow properties of bulk materials and particularly, biomass materials has been a major drawback in the design of storage systems and has been a factor in many poor designs and flow problems. Earlier work by B.C. Research (1) led to the development of special test equipment and procedures for flow characterization of biomass materials. This fundamental work has greatly enhanced our understanding of the flow of biomass in storage bins and has resulted in simplifications in bin geometry which, in turn, has led to unique developments in discharge feeder design.

The 760 mm diameter ring shear cell that is currently used by B.C. Research is an expensive tester and requires a fair amount of experience to obtain meaningful data from it. Also, it takes approximately one week to do a series of tests on a sample of material, making it time-consuming, and expensive to operate the BCR tester. Consequently, the number of tests done, even for a fairly large bin, are limited to one or two. For small storage systems, the high cost of the tests is often not justified, making it necessary to resort to guesswork and previous experience.

This lack of availability of proper design criteria to researchers and designers at a reasonable cost leads to a lack of understanding of the fundamentals and to poor design of materials handling systems. This project was prompted by a need for a simpler and an inexpensive tester which gives quick results and can be related to results from the ring shear cell.

CONCEPT OF THE NEW TESTER

The concept of the new tester is shown schematically in Figure 1 and essentially consists of a deck with a slot in the middle. The width of the slot is expanded gradually until the material cannot support itself across the slot and a rat-hole is formed (Figure 1(b)). The opening of the slot

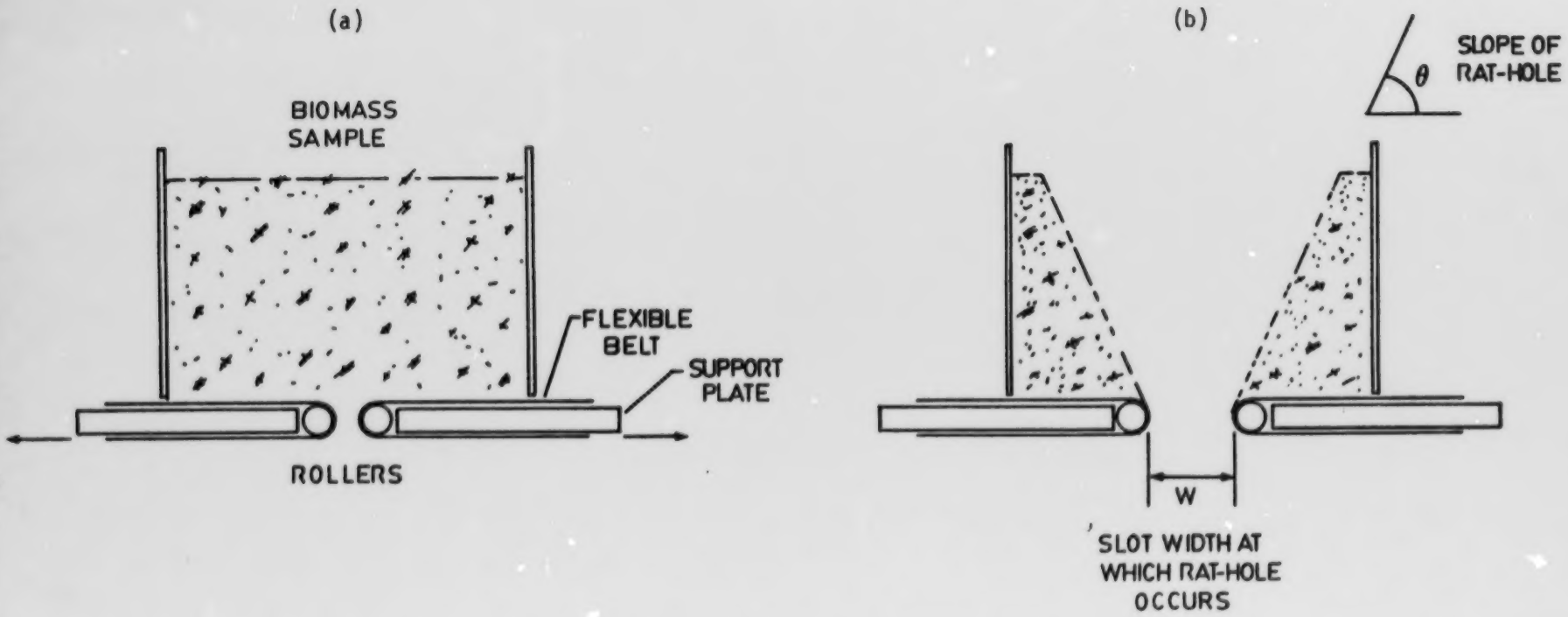


Figure 1 Concept of the UKAF Flow Tester

is achieved without any friction between the deck and the material above it by supporting the flexible part of the deck over a sliding plate and pulling on the lower part of the flexible belt to widen the slot. As a result, there is no friction between the top of the flexible belt and material above it. The width of the slot at which the rat-hole occurs is related to the flowability of the biomass sample. The larger the slot width required, the poorer the flow characteristics of the material being tested.

METHOD

DESIGN AND CONSTRUCTION OF TESTER

The photograph in Figure 2 is of a designed and constructed tester. Figure 3 shows an isometric drawing of the tester; construction details of the tester are shown in Figures 4 and 5.

The tester essentially consists of a 760 mm long x 500 mm wide (maximum) x 460 mm high acrylic box centered over a deck with an expanding slot. The deck consists of two horizontal plates which can slide in and out to form a slot running the width of the box. On each half of the deck, a flexible belt was placed on top and looped back via the middle of the deck to the underside of the deck. The belt allowed opening and closing of the slot without disturbing the material under test in the acrylic box. The width of the acrylic box could be varied by moving one of the 760 mm long plates in or out.

Opening and closing of the slot was done by means of a 25 mm diameter rod, threaded on one side with left-hand acme thread and on the other side with right-hand acme thread. The rod was rotated inside two appropriately threaded driving arms connected to the two sliding plates of the tester deck by a 0.015 kW (1/50 HP) Bodine geared motor with a controller to vary and reverse the speed of the motor. The speed with which the slot could be opened or closed could be varied from a minimum of zero to a maximum of 200 mm/min.

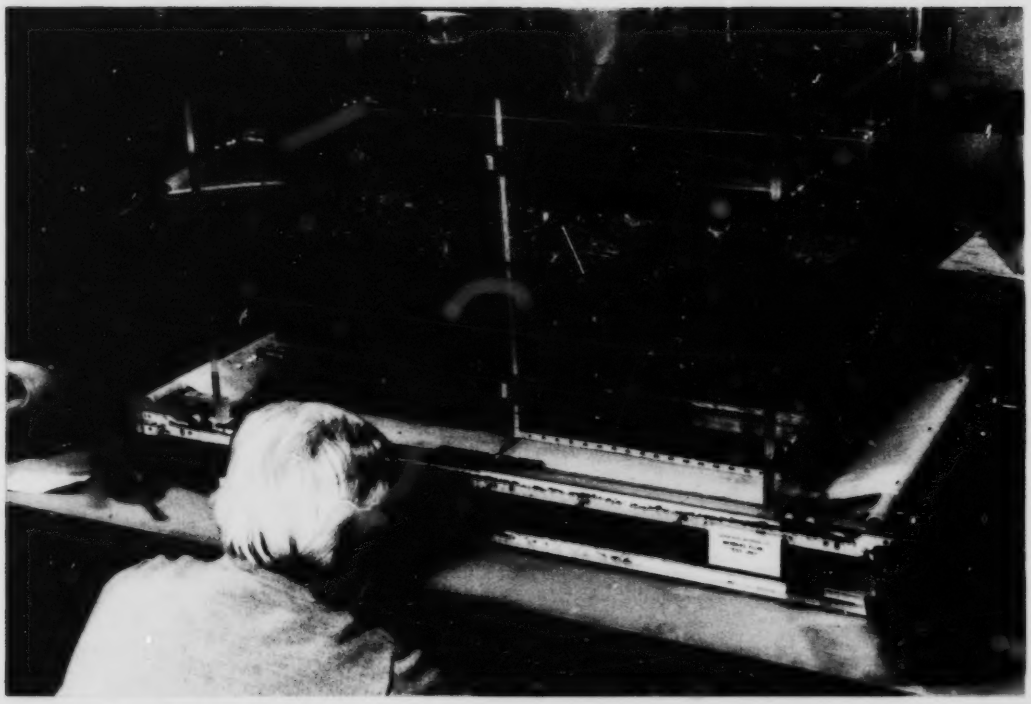


Figure 2 Photograph of the UKAF Flow Tester

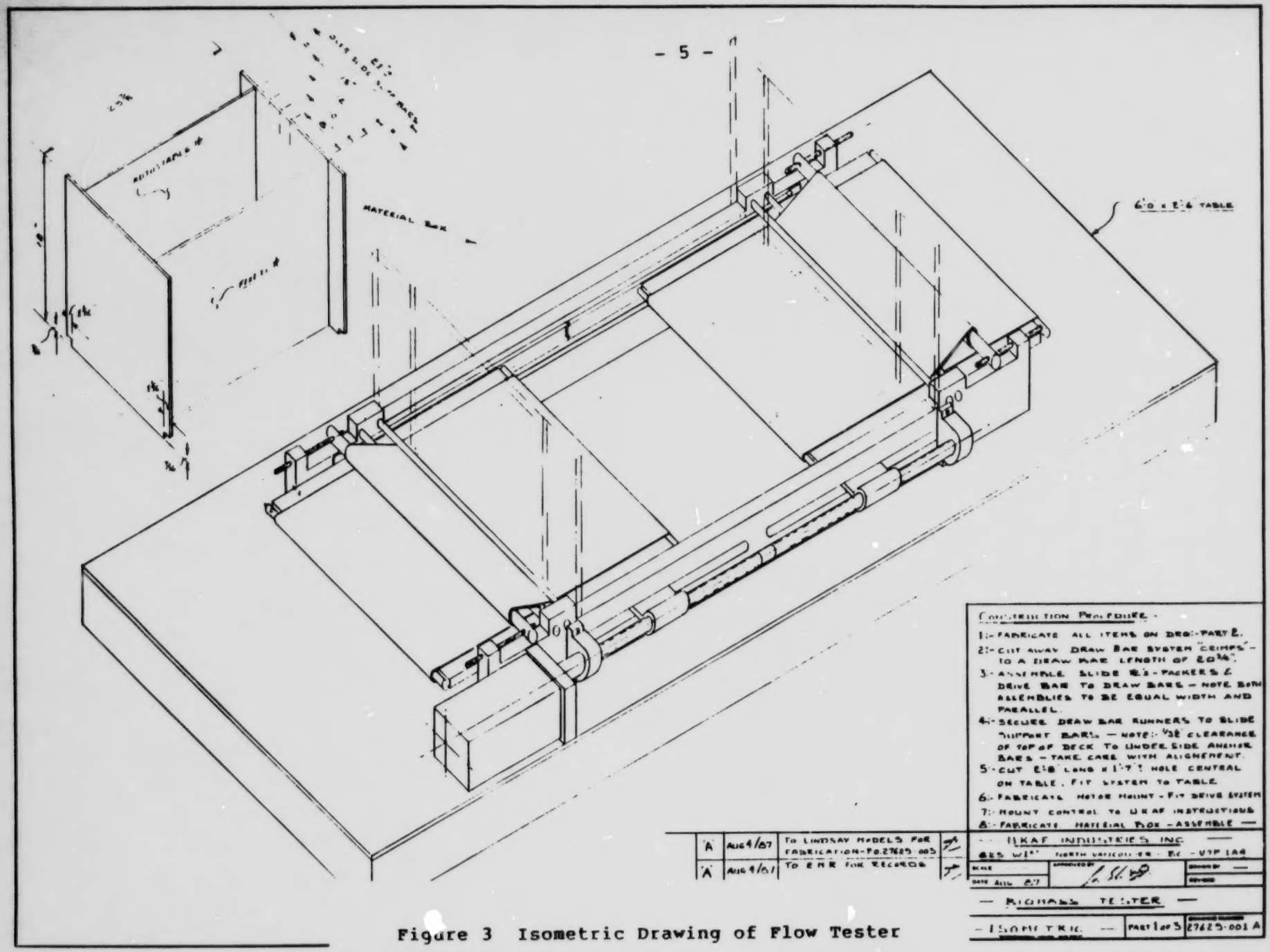

MATERIAL BOX
6'0 x 2'6 TABLE
CONSTRUCTION PROCEDURE :-
1:- FABRICATE ALL ITEMS ON DRG:- PART 2.
2:- CUT AWAY DRAW BAR SYSTEM "CRIMPS" - TO A DRAW BAR LENGTH OF 20 3/4".
3:- ASSEMBLE SLIDE B.S - PACKERS & DRIVE BAR TO DRAW BARS - NOTE BOTH ASSEMBLIES TO BE EQUAL WIDTH AND PARALLEL.
4:- SECURE DRAW BAR RUNNERS TO SLIDE SUPPORT BARS - NOTE:- 1/32" CLEARANCE OF TOP OF DECK TO UNDER SIDE ANCHOR BARS - TAKE CARE WITH ALIGNMENT.
5:- CUT 2'8" LONG x 1'7" HOLE CENTRAL ON TABLE. FIT SYSTEM TO TABLE.
6:- FABRICATE MOTOR MOUNT - FIT DRIVE SYSTEM
7:- MOUNT CONTROL TO U.K.A.F. INSTRUCTIONS
8:- FABRICATE MATERIAL BOX - ASSEMBLE
A Aug 4/87 To Lindsay Models for fabrication - Fo.27625.003
A Aug 4/87 To E.M.R. for Records
U.K.A.F. INDUSTRIES INC.
- MICHAELS TESTER -
- ISOMETRIC -
PART 1 of 3
27625-001 A

Figure 3 Isometric Drawing of Flow Tester

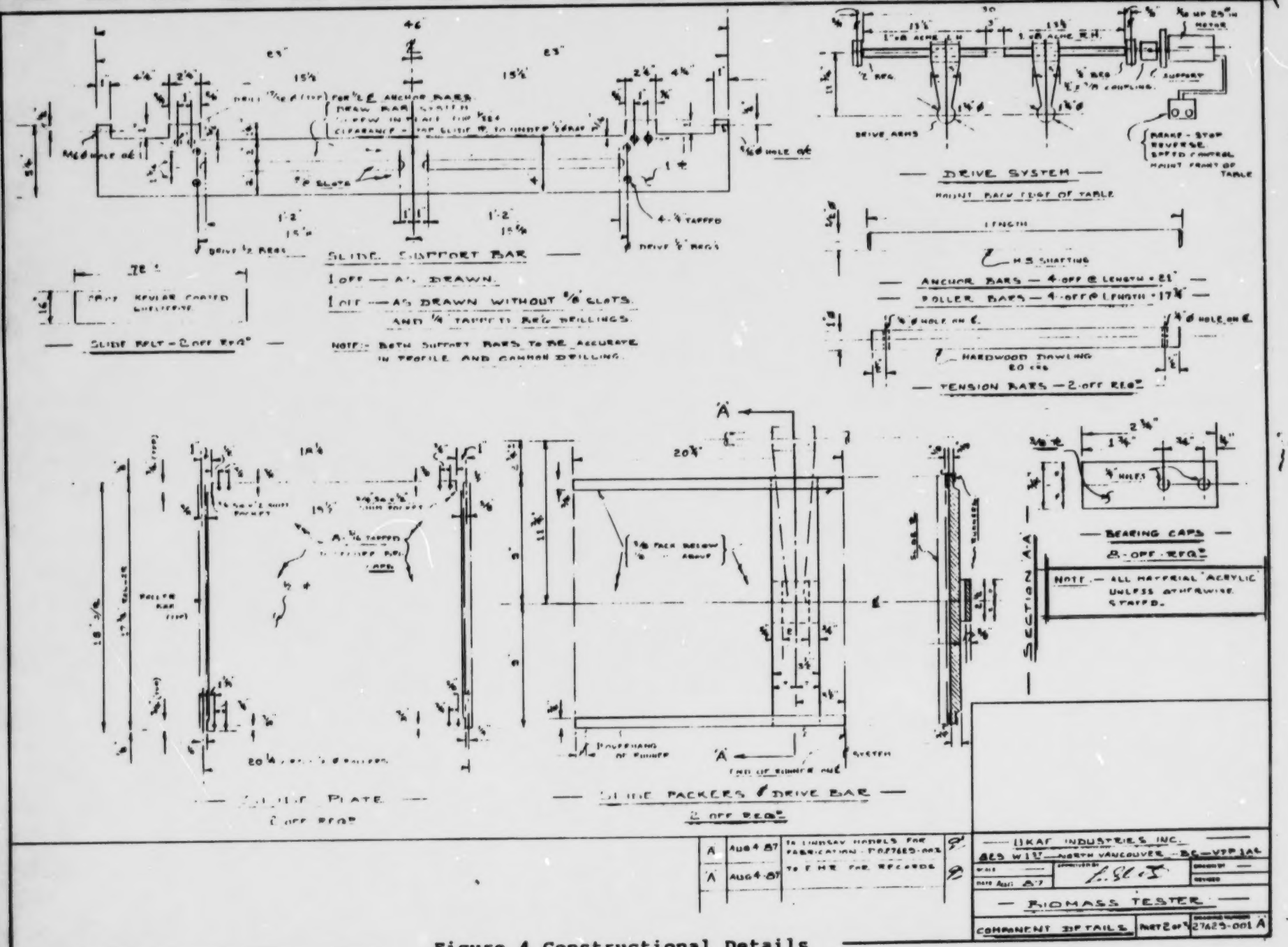

SLIDE SUPPORT BAR
1 OFF — A's DRAWN.
1 OFF — A's DRAWN WITHOUT 5/8 SLOTS AND 1/4 TAPPED REG'D DRILLINGS.
NOTE:- BOTH SUPPORT BARS TO BE ACCURATE IN PROFILE AND CANNON DRILLING.
SLIDE BELT - 2 OFF REQ'D
DRIVE SYSTEM
ANCHOR BARS — 4 OFF @ LENGTH = 21"
ROLLER BARS — 4 OFF @ LENGTH = 17 3/4"
TENSION BARS — 2 OFF REQ'D
SLIDE PLATE
1 OFF REQ'D
SLIDE PACKERS & DRIVE BAR
2 OFF REQ'D
BEARING CAPS
8 OFF REQ'D
NOTE — ALL MATERIAL ACRYLIC UNLESS OTHERWISE STATED.
SECTION A-A
A | AUG 4 87 | TO LINDSAY MODELS FOR FABRICATION - DRAWING 27625-002
A | AUG 4 87 | TO FILE FOR RECORDS
IKAF INDUSTRIES INC.
865 W 1ST — NORTH VANCOUVER — B.C. — V7P 1A2
BIOMASS TESTER
COMPONENT DETAILS
SHEET 2 OF 4
27625-001 A

Figure 4 Constructional Details

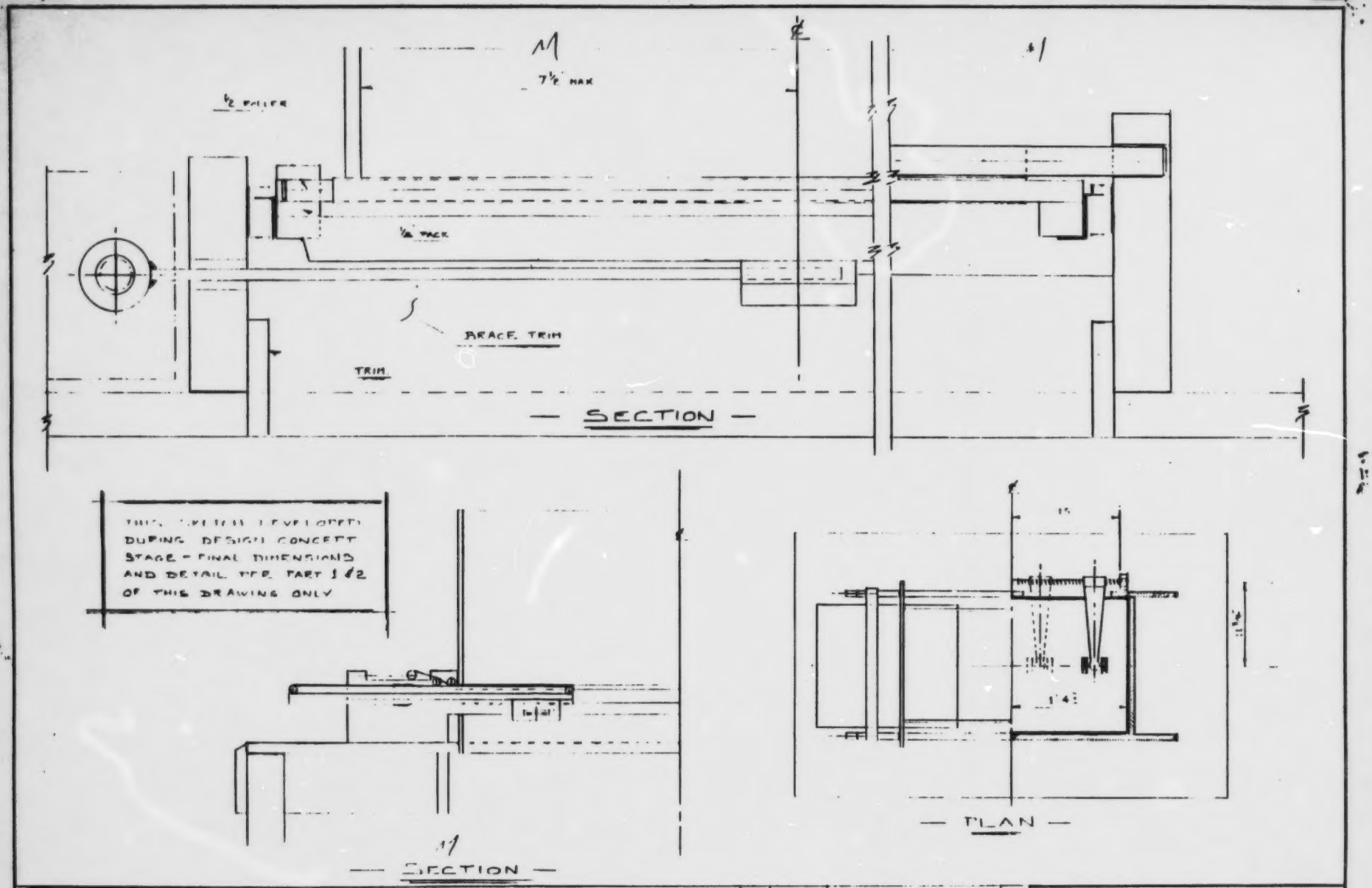


Figure 5 Assembly and Operational Details

TEST PROCEDURE

Several preliminary tests with biomass samples were done in order to establish a procedure which gave reasonable and reproducible test results. The following parameters were varied for the preliminary tests:

- height of material in the tester,
- width of tester,
- speed of opening of slot.

The height of test material was fixed at 22 cm (tester half full), and the width of the tester was fixed at 25 cm for the tests, as these gave satisfactory results. The speed of opening of the slot was fixed at 100 mm/min (50% of the maximum speed). The tester was also found to be sensitive to the way it was loaded with material - gentle loading of material in layers was found to be necessary in order to avoid size segregation of the material and variation in the strength of material across the width of the tester.

Final Test Procedure

The final test procedure arrived at was as follows:

With the slot closed, the tester was carefully loaded with a representative sample of the biomass material to be tested. A long box, approximately the same length as the tester was used to pour material into the tester in layers until the material reached a height of 22 cm (indicated by a line marked horizontally on the tester [see Figure 2]).

A container was placed under the slot to collect material discharged. The motor to open the slot was turned on to operate at 100 mm/min. As the slot opened, a small quantity of material fell to form a dome as shown in Figure 6. As the slot widened, the dome deepened (see Figure 7). At the point when the slot was too wide for the material to support itself over it, the material above the dome collapsed

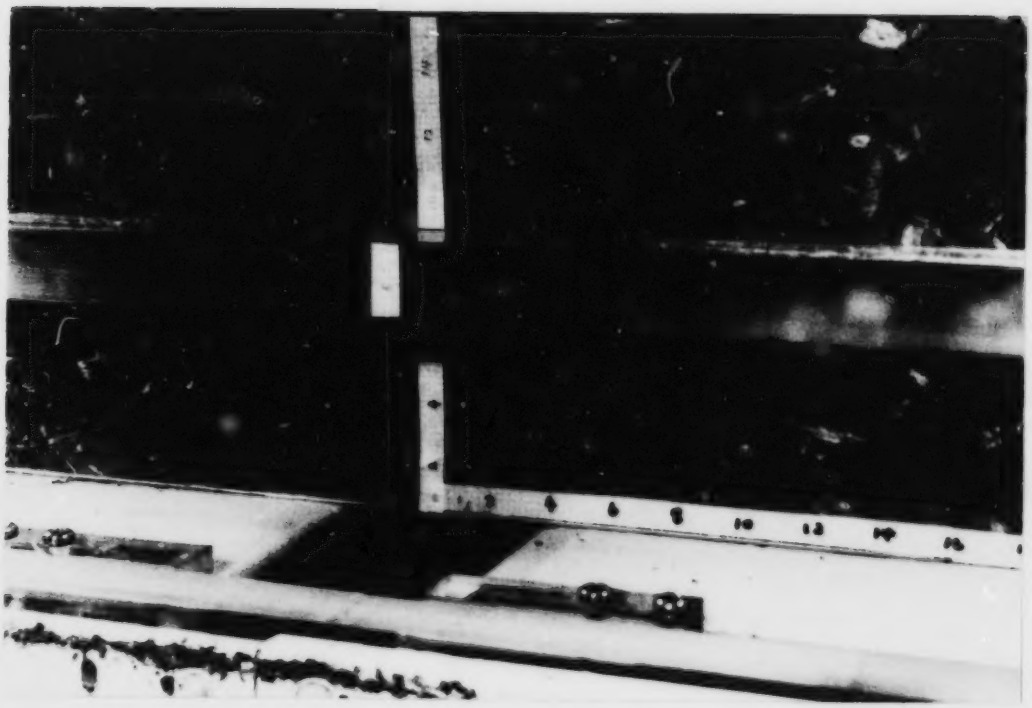


Figure 6 Formation of Dome as the Slot Started to Expand

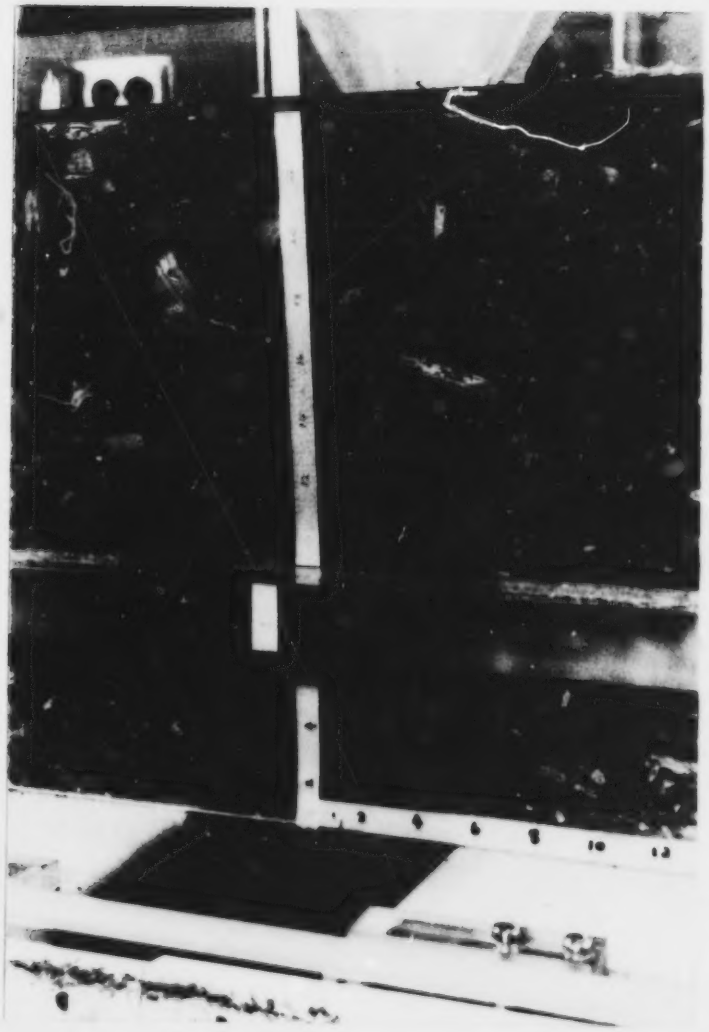


Figure 7 View of Dome on the Verge of Collapsing

completely (Figure 8). The tester motor was stopped at this point and the width of the slot recorded. The weight of material collected under the tester was also recorded.

The shape of the dome formed was also found to be significant - free flowing material (e.g., sawdust) formed a deeper and narrower dome, whereas wood chips formed a shallower dome. The depth of the dome at 10 cm and 20 cm width of the arch was also recorded. The depth was not always easy to determine, particularly for coarse material as the shape of the dome varied somewhat across the width of the tester.

For each sample of biomass, the above tests were done three times and the middle value of the results was taken as the final value for use in calculations.

TESTS

Tests were done for a range of biomass samples, using the new tester above. Altogether, 14 tests were done on samples of hog fuel, wood chips, sawdust, shavings and peat. Tests were also done on two non-biomass materials for comparison purposes.

To determine the effect of storage at rest, several time consolidation tests were also done by leaving the material in the tester for a pre-determined period of time before opening the slot. During the period the material was left in the tester, a cover was placed on the tester to prevent drying out of the material. Because of the long periods required for these tests, it was not possible to do the tests three times as in the case of "instantaneous" consolidation tests.

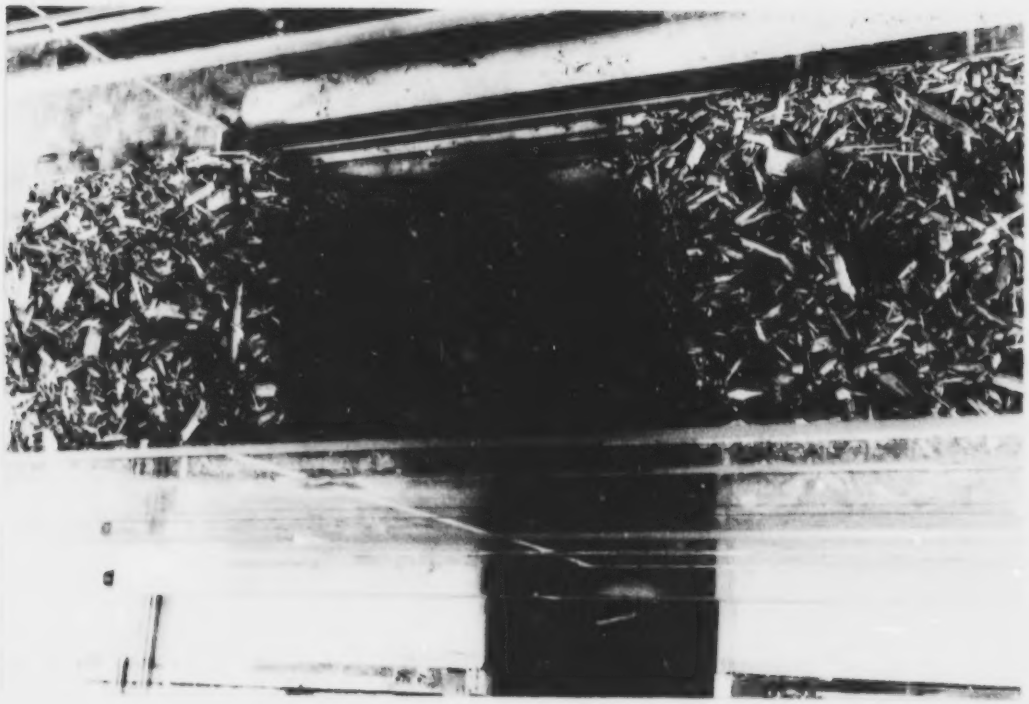


Figure 8 View of Rat-hole from Top

Tests on the Ring Shear Cell

For each of the biomass samples tested above, tests were also done on the ring shear cell (1) to allow a comparison of the results. The 260 mm diameter ring shear cell was used for most of the samples. For the coarser wood chips samples, the 760 mm diameter cell was used for the tests.

Details of the ring shear cells and the test procedures used are described in more detail in reference (1).

Other Tests

To characterize the biomass samples, the moisture content, particle size distribution and bulk density were also determined for each sample.

RESULTS

Results of tests with the new tester are shown in Table 1. Results of tests with the ring shear cell are shown in Table 2.

Time consolidation tests to determine the effect of storage at rest are shown in Table 3.

Figure 8 shows a comparison of the results from the new tester to those from the ring shear cell.

Detailed results of the ring shear cell tests and particle size distribution are given in the Appendix.

TABLE 1. RESULTS OF TESTS ON THE UKAF TESTER

SAMPLE NO.	MATERIAL	HEIGHT OF DOME, cm @ 10 cm Width	HEIGHT OF DOME, cm @ 20 cm Width	Final Half Slot Width, cm	Slot Width cm	WEIGHT OF MATL. of collapsed arch, kg	% Moist	Mean Particle size, mm
A1	Hemlock hog fuel	4.0 5.0 5.0 ===== Mid 5.0	=====	12.6 8.0 8.8 ===== 8.8	17.6	7.014 4.363 5.961 ===== 5.961	49.8	34
A2	Hemlock sawdust	4.5 6.0 6.5 ===== Mid 6.0	=====	6.4 5.8 5.6 ===== 5.8	11.6	3.010 3.375 3.192 ===== 3.192	58.9	1.4
A3	Hemlock wood chips	3.0 3.5 4.0 ===== Mid 3.5	=====	15.5 10.4 12.6 ===== 12.6	25.2	6.195 5.687 6.070 ===== 6.070	53.9	14
A4	Cedar hog fuel	0.5 0.5 1.0 ===== Mid 0.5	=====	17.0 15.6 18.0 ===== 17.0	34.0	2.710 2.324 2.368 ===== 2.368	41.8	2.7
A5	Cedar sawdust	6.0 7.0 7.0 ===== Mid 7.0	- - - ===== -	8.2 6.2 10.2 ===== 8.2	16.4	3.671 2.989 3.784 ===== 3.671	60.0	1.5
A6	Wood chips	4.5 5.5 6.0 ===== Mid 5.5	10.0 - - ===== 10.0	13.8 9.4 7.2 ===== 9.4	18.8	4.591 2.859 3.479 ===== 3.479	55.2	14
A7	Shavings	0.5 0.5 0.0 ===== Mid 0.5	- 6.0 6.0 ===== 6.0	20.2 21.6 19.7 ===== 20.2	40.4	2.473 2.410 2.268 ===== 2.410	31.0	3.5
A8	Shavings	2.0 2.0 1.5 ===== Mid 2.0	=====	18.4 15.0 14.8 ===== 15.0	30.0	1.471 1.496 1.371 ===== 1.471	28.6	3.2

TABLE 1. RESULTS OF TESTS ON THE UKAF TESTER (CONT.)

SAMPLE NO.	MATERIAL		HEIGHT OF DOME, cm @ 10 cm Width	@ 20 cm Width	Final Half Slot Width, cm	Slot Width cm	WEIGHT OF MATL. of collapsed arch, kg	% Moist	Mean Particle size, mm
A9	Sawdust		4.0	-	12.6		3.662		
			2.0	-	11.0		3.254		
			3.0	-	13.6		3.049		
			-----	-----	-----		-----		
		Mid	3.0		12.6	25.2	3.254	39.6	0.2
A10	Dry peat		5.5	-	9.2		1.627		
			3.0	-	8.4		1.694		
			4.0	-	8.2		1.535		
			-----	-----	-----		-----		
		Mid	4.0		8.4	16.8	1.627	38.2	0.4
A11	Perlite Ore		-	-	0.6		2.683		
			-	-	0.6		2.390		
			-	-	0.8		2.158		
			-----	-----	-----		-----		
		Mid			0.6	1.2	2.390	2.0	-
A12	Iron Ore		-		2.8		2.468		
			-		3.2		2.906		
			-		3.5		3.127		
			-----	-----	-----		-----		
		Mid	-		3.2	6.4	2.906	-	-
A13	Gold Ore		-	-	1.2		2.437		
			-	-	1.1		2.401		
			-	-	1.2		2.292		
			-----	-----	-----		-----		
		Mid		-	1.2	2.4	2.401	2.0	-
A14	Stringy cedar				19.0		5.475		
					17.0		3.886		
					24.0		7.959		
			-----	-----	-----		-----		
		Mid			19.0	38.0	5.475	67.0	0.2
B1	Hemlock hog fuel								
			-----	-----	-----		-----		
		Mid			12.8	25.6		7.0	34.0
B2	Hemlock sawdust								
			-----	-----	-----		-----		
		Mid			6.8	13.6		11.0	1.4

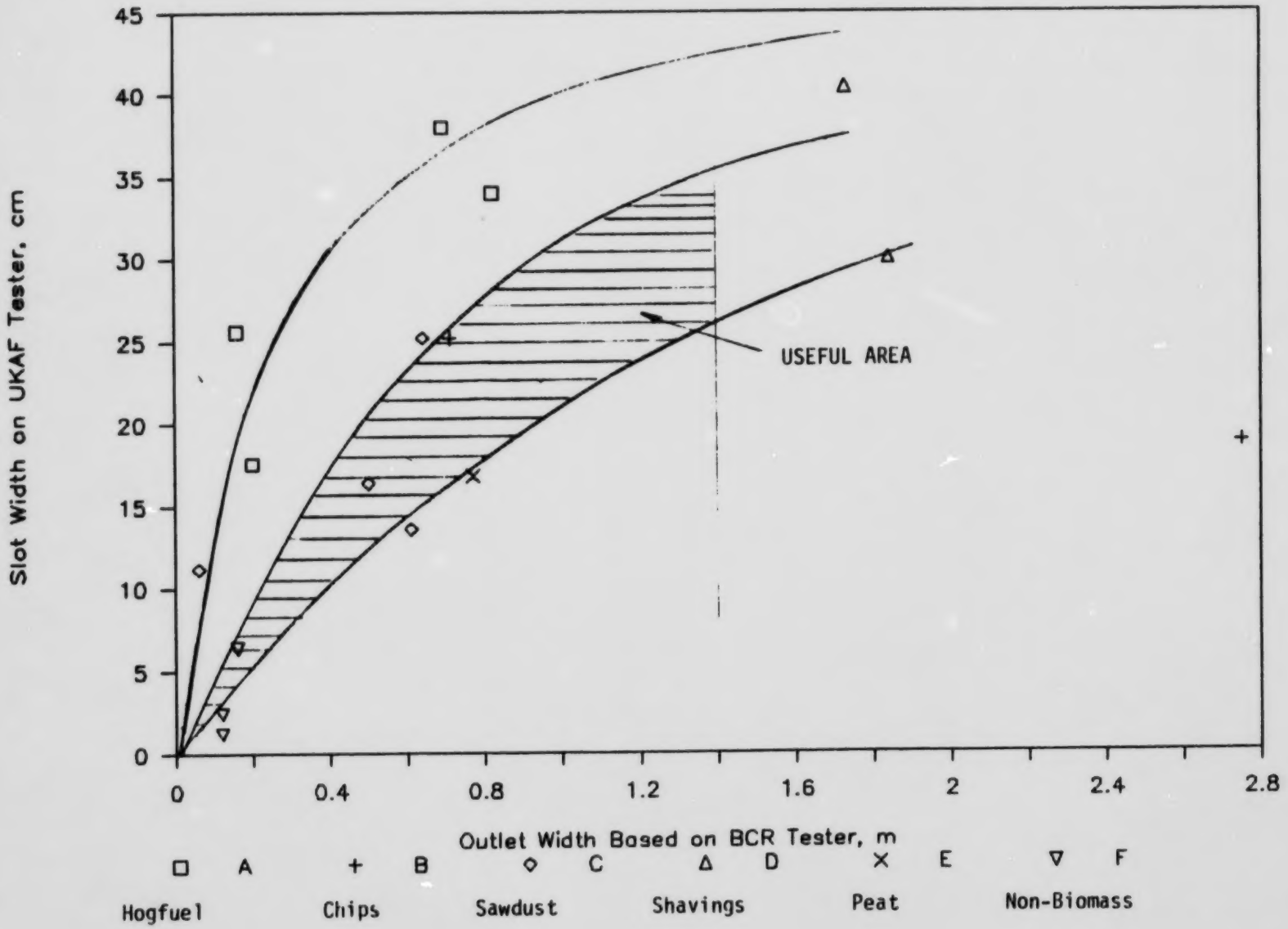
TABLE 2. RESULTS OF TESTS ON THE RING SHEAR CELL

SAMPLE NO.	MATERIAL	BULK DENSITY g/cu cm Poured	BULK DENSITY g/cu cm Tapped	% Moisture	Mean Particle Size, mm	Crit. Unconfined Yield Stress g/sq cm	Mass Flow Outlet, m
A1	Hemlock hog fuel	0.48	0.60	49.8	34.0	8	0.20
A2	Hemlock sawdust	0.37	0.47	58.9	1.4	2	0.06
A3	Hemlock chips	0.27	0.32	53.9	14.0	26	0.71
A4	Cedar hog fuel	0.14	0.23	41.8	2.7	10	0.82
A5	Cedar sawdust	0.28	0.33	60.0	1.5	12	0.50
A6	Wood chips	0.23	0.25	55.2	14.0	55	2.75
A7	Shavings	0.08	0.12	31.0	3.5	12	1.73
A8	Shavings	0.05	0.07	28.6	3.2	8	1.84
A9	Sawdust	0.18	0.22	39.6	0.2	10	0.64
A10	Dry peat	0.12	0.15	38.2	0.4	8	0.77
A11	Perlite Ore	1.37	1.45	2.0	-	12	0.12
A12	Iron Ore	1.68	2.33	-	-	23	0.16
A13	Gold Ore	1.37	1.45	2.0	-	12	0.12
A14	Stringy cedar	0.20	0.33	67.0	0.2	12	0.69
B1	Hemlock hog fuel	0.22	0.25	7.0	34.0	3	0.16
B2	Hemlock sawdust	0.15	0.18	11.0	1.4	8	0.61

TABLE 3. RESULTS OF TIME CONSOLIDATION TESTS

SAMPLE NO.	MATERIAL	Time Consol.	SLOT WIDTH, cm		Mass Flow Outlet, m from Shear Tests		Mass Flow Outlet, m from UKAF Tester	
			Zero Time	Time Consol.	Zero Time	Time Consol.	Zero Time	Time Consol.
TA1	Hemlock hog fuel	16 Hours	17.6	19.6	0.20	0.65	0.4	0.5
TA2	Hemlock sawdust	16 Hours	11.2	21.6	0.06	0.42	0.2	0.5
TA3	Hemlock wood chips	1.5 Hours	25.2	27.6	0.71	1.15	0.7	0.8

FIGURE 9. SUMMARY RESULTS
COMPARISON OF RESULTS ON THE TWO TESTERS



DISCUSSIONS

Results of slot width from the UKAF flow tester showed that the tester was sensitive to the flow characteristics of the biomass samples tested - i.e., poorer flowing materials such as hogfuel required larger slot widths than the more free flowing sawdust samples. The results were also fairly reproducible - the variations in the three points that were done for each test were well within the acceptable limits for such variable materials.

A comparison of the results of the slot widths from the UKAF tester with the mass flow outlet width, calculated from the ring shear cell (see Figure 9), showed that there was a definite relationship. As the calculated outlet width increased, the slot width on the UKAF tester increased also. As expected, the relationship was not linear - the increase in the slot width for the first part of the curve (up to 1 m outlet width) was much more rapid than for the higher part of the curve. The majority of bin outlet dimensions are expected to be less than 1 m as determined from an earlier study.

The comparison of the results in Figure 9 also showed a considerable amount of scatter. The scatter is due to the cumulative effect of the variability of results from both the UKAF tester and the ring shear cell. The ring shear cell which is used as a standard for the comparisons, is prone to giving results which are often not well-defined, requiring skill and experience in interpretation. This variability is illustrated in the graphs of the flow function curves shown in the Appendix. Hence, the scatter in the results shown in Figure 9 is not surprising.

The mass flow hopper outlet width can be predicted from Figure 9, using the slot width obtained from the UKAF tester. Three curves are shown in Figure 9, the middle curve representing the average results and the other two curves representing the level of safety required in interpreting the results of the tester. The top curve gives bin outlet dimensions which are too small if particle size and capacity are taken into consideration. Hence, from a practical point

of view, the shaded area in Figure 9 is considered to be of most use.

The new tester was also found to be sensitive to the increase in the strength of biomass during storage at rest as seen in Table 3. A comparison of the results of time consolidation tests from the new tester to those from the ring shear cell show good correlation.

The new tester provides a relatively inexpensive and quick test for characterizing biomass materials in terms of flow properties and estimating critical bin design parameters for reliable flow. The time required to do a series of tests on a sample of biomass was approximately 10 minutes (compared to two to five days on the ring shear cell). The cost of building such a tester (materials only) was less than one-fifth of the cost of a 260 mm diameter ring shear cell. The 760 mm diameter ring shear cell, which is estimated to be approximately five times that of the 260 mm cell, is prohibitive to the average user.

The new tester is not intended to replace the ring shear cell, but rather to complement it.

CONCLUSIONS

1. The UKAF flow tester provides a simple, quick and an inexpensive system of assessing the flow characteristics of biomass materials. The results from the tester can be used for estimating critical bin design parameters to avoid flow problems, as well as comparing different biomass materials from a flow point of view.

2. The tester as designed worked satisfactorily, and the constructional details provided in this report are recommended for others who may wish to build such a tester. The procedure used for the tests, as described in the METHOD section, is also recommended, particularly maintaining the height of the test material above the slot at 22 cm to allow comparison of the test results.

3. The width of the slot can be used for estimating the outlet width of a mass flow hopper (plain flow - rectangular hopper with two sloping and two vertical sides) as follows:

SLOT WIDTH ON UKAF Tester cm	FLOWABILITY	RECOMMENDED MASS FLOW OULTLET WIDTH m
<10	Very Free	0.30 - 0.40
10 - 15	Free Flowing	0.35 - 0.60
15 - 20	"Normal"	0.60 - 1.00
20 - 25	Difficult	1.00 - 1.25
>25	Very Difficult	>1.30

The majority of biomass materials fit into the first three categories.

REFERENCES

1. Bundalli, N. 1982. Bin and Silo Design for Biomass Materials, Phase I. Enfor Project C-130, Enfor Secretariat, Ottawa, Ontario, 366 pp.

2. Bundalli, N. 1985. Bin and Silo Design for Biomass Materials, Phase III. Bioenergy Development Program, EMR, Ottawa, Ontario.

APPENDIX

Table A1. Shear Test Results - Hemlock Hogfuel

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	18.0		
		1.5	4.1
		2.9	5.3
		4.3	8.8
		6.2	9.5
		11.8	15.9
		13.2	15.8
		14.6	18.0
24.3	28.1		
		1.5	4.9
		2.9	8.6
		4.3	12.0
		9.0	18.8
		14.6	21.1
		21.0	24.8
		24.3	28.1
45.0	52.8		
		1.5	6.1
		2.9	7.7
		4.3	9.8
		9.0	18.2
		18.2	32.2
		33.9	47.6
		45.0	52.8
60.3	68.5		
		1.5	4.9
		2.9	7.6
		4.3	12.0
		9.0	15.1
		24.3	36.5
		45.0	53.3
		60.3	68.5
85.6	103.9		
		1.5	6.3
		4.3	15.3
		24.3	48.0
		45.0	66.2
		60.3	82.4
		70.4	98.1
		85.6	103.9
115.9	140.2		
		1.5	6.1
		4.3	13.4
		24.3	52.9
		45.0	62.7
		70.4	97.5
		85.6	117.6
		115.9	140.2

Table A2. Flow Properties - Hemlock Bogfuel

NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	18.0	40.8	13.2	3.10	55.5	59.29	1.57	.46
24.3	28.1	68.3	22.3	3.07	55.7	59.29	2.66	.78
45.0	52.8	125.3	40.1	3.13	55.3	59.29	4.78	1.41
60.3	68.5	152.1	39.6	3.84	52.0	59.29	4.72	1.39
85.6	103.9	243.7	81.4	2.99	56.1	59.29	9.70	2.86
115.9	140.2	316.2	97.2	3.25	54.7	59.29	11.58	3.41

SHEAR INDEX (N) = 1.44

YIELD LOCUS	PERCENT FIT
1	99.6
2	98.7
3	99.3
4	99.5
5	99.6
6	99.2

Table A3. Time Consolidation Results - Hemlock Hogfuel

CONSOLIDATION		YIELD POINT		<----------FLOW PROPERTIES---------->					
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS INST	MAJ PRINC CONSOL'N STRESS TIME	UNCONFIN YIELD STRESS	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	DEG	DEG	G/SQ CM
CONSOLIDATION PERIOD 2 HRS									
45.0	51.3	45.0	58.0	125.2	133.8	49.4	58.3	59.4	5.87
115.9	130.9	115.9	134.2	315.7	309.7	91.7	54.3	59.4	10.90
CONSOLIDATION PERIOD 16 HRS									
14.6	19.6	14.6	23.3	40.8	54.6	30.0	66.6	59.4	3.57
60.3	70.4	60.3	78.7	152.0	181.7	68.7	58.7	59.4	8.17

SHEAR INDEX (N) = 1.44

COHESION/ TENSILE STRENGTH = 3.40

Figure A1. Material & Hopper Flow Factors - Hemlock Hogfuel

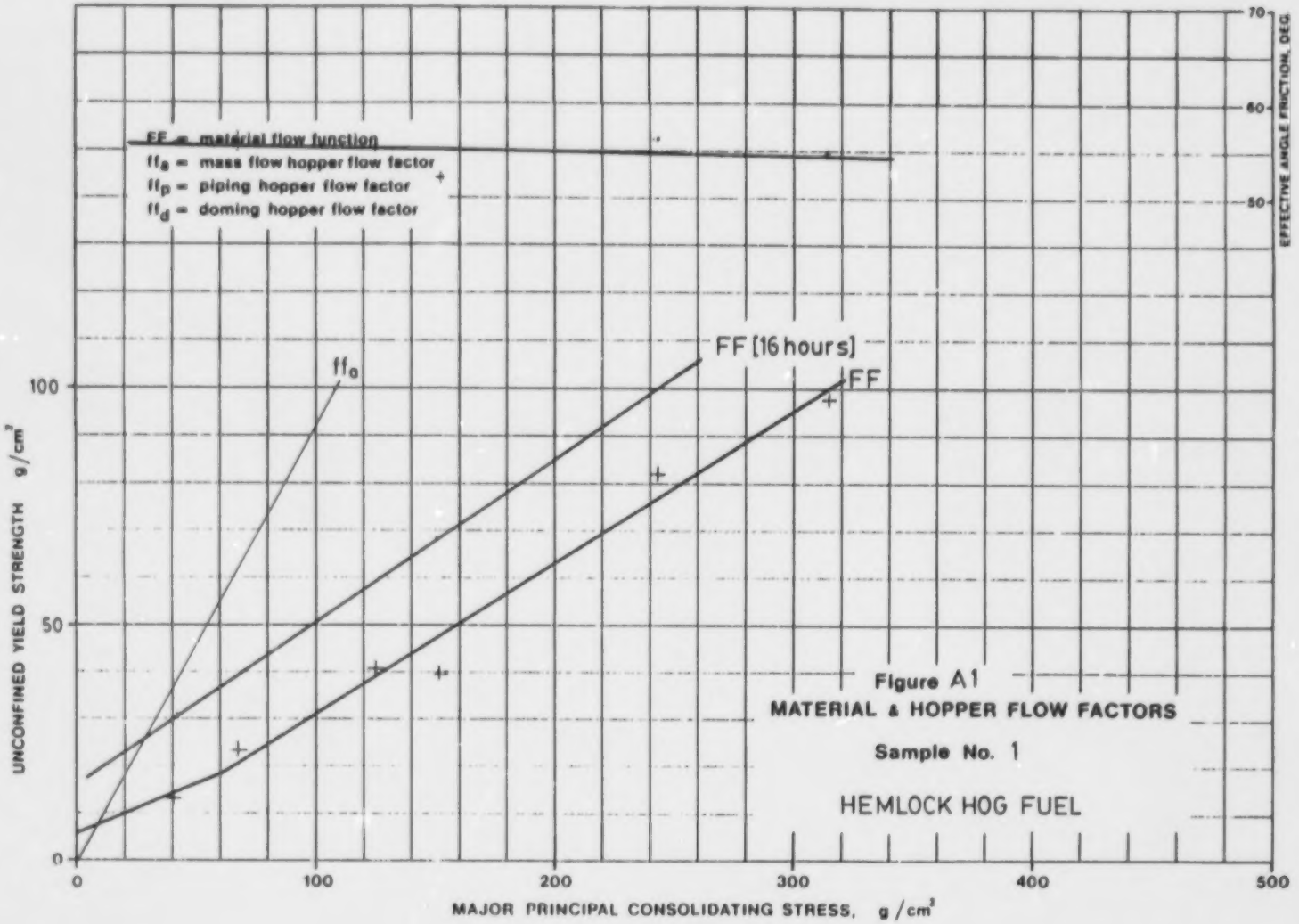


Figure A2. Particle Size Distribution - Hemlock Hogfuel

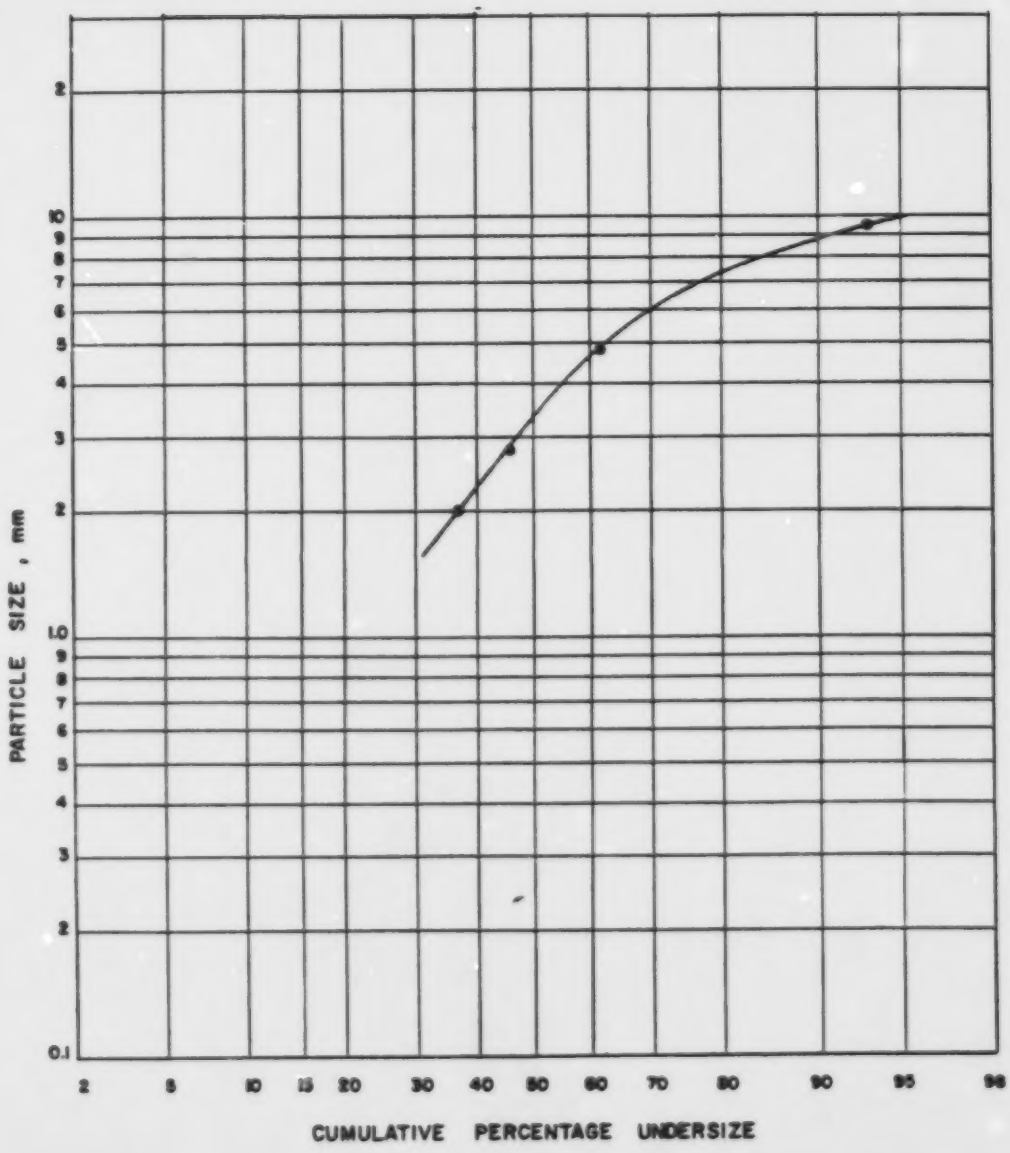


Table A4. Shear Test Results - Hemlock Sawdust

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	14.6		
		1.5	3.2
		2.9	4.5
		4.3	6.1
		6.2	7.4
		11.8	11.5
		13.2	12.7
		14.6	14.6
24.3	23.8		
		1.5	3.2
		2.9	4.5
		4.3	6.4
		9.0	12.3
		14.6	17.8
		21.0	23.5
		24.3	23.8
45.0	46.9		
		1.5	4.5
		2.9	6.8
		4.3	10.1
		9.0	14.7
		18.2	25.7
		33.9	37.9
		45.0	46.9
60.3	69.4		
		1.5	6.0
		2.9	9.8
		4.3	14.3
		9.0	19.4
		24.3	38.3
		45.0	60.1
		60.3	69.4
85.6	95.1		
		1.5	5.5
		4.3	9.4
		24.3	39.4
		45.0	56.6
		60.3	69.3
		70.4	76.8
		85.6	95.1

Table A5. Flow Properties - Hemlock Sawdust

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	14.6	33.5	5.1	6.54	46.9	57.71	.67	.24
24.3	23.8	58.7	10.5	5.59	48.8	57.71	1.37	.50
45.0	46.9	111.1	21.3	5.23	49.6	57.71	2.78	1.01
60.3	69.4	168.0	44.1	3.81	53.7	57.71	5.77	2.10
85.6	95.1	215.4	43.4	4.96	50.3	57.71	5.68	2.06

SHEAR INDEX (N) = 1.35

YIELD LOCUS	PERCENT FIT
1	99.8
2	99.5
3	99.9
4	99.8
5	99.7

Table A6. Time Consolidation Results - Hemlock Sawdust

CONSOLIDATION		YIELD POINT		<----------FLOW PROPERTIES----------					
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS INST	MAJ PRINC CONSOL'N STRESS TIME	UNCONFIN YIELD STRESS	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		G/SQ CM	DEG	DEG	G/SQ CM
CONSOLIDATION PERIOD 1.5 HRS									
24.3	23.2	24.3	25.3	58.7	60.0	11.6	49.6	57.5	1.52
CONSOLIDATION PERIOD 20 HRS									
85.6	93.8	85.6	102.0	215.2	240.5	66.0	54.3	57.5	8.69
CONSOLIDATION PERIOD 66 HRS									
45.0	48.8	45.0	52.9	111.1	124.7	33.1	53.8	57.5	4.36

SHEAR INDEX (N) = 1.35

COHESION/ TENSILE STRENGTH = 2.72

Figure A3. Material & Hopper Flow Factors - Hemlock Sawdust

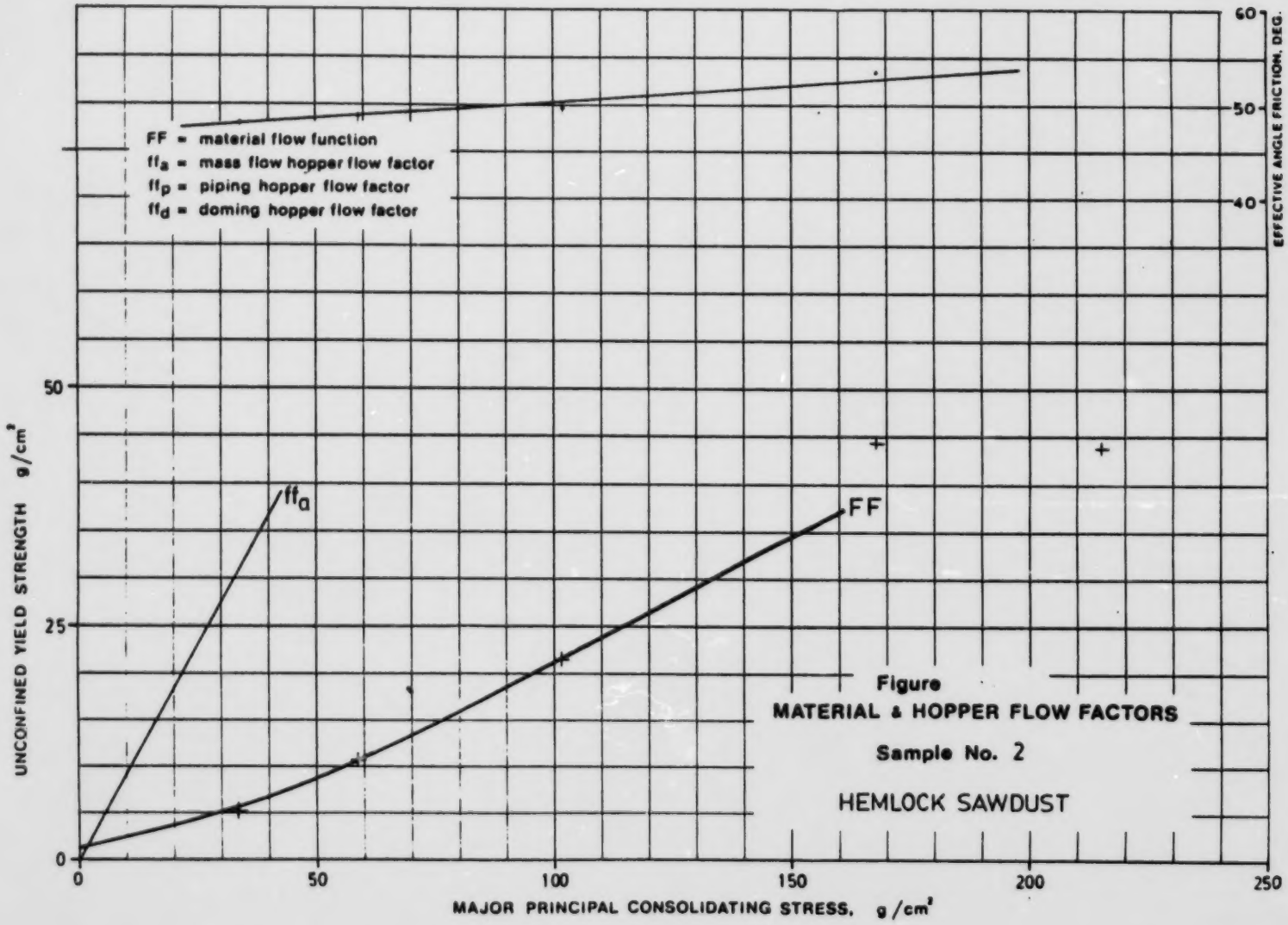


Figure A4. Particle Size Distribution - Hemlock Sawdust

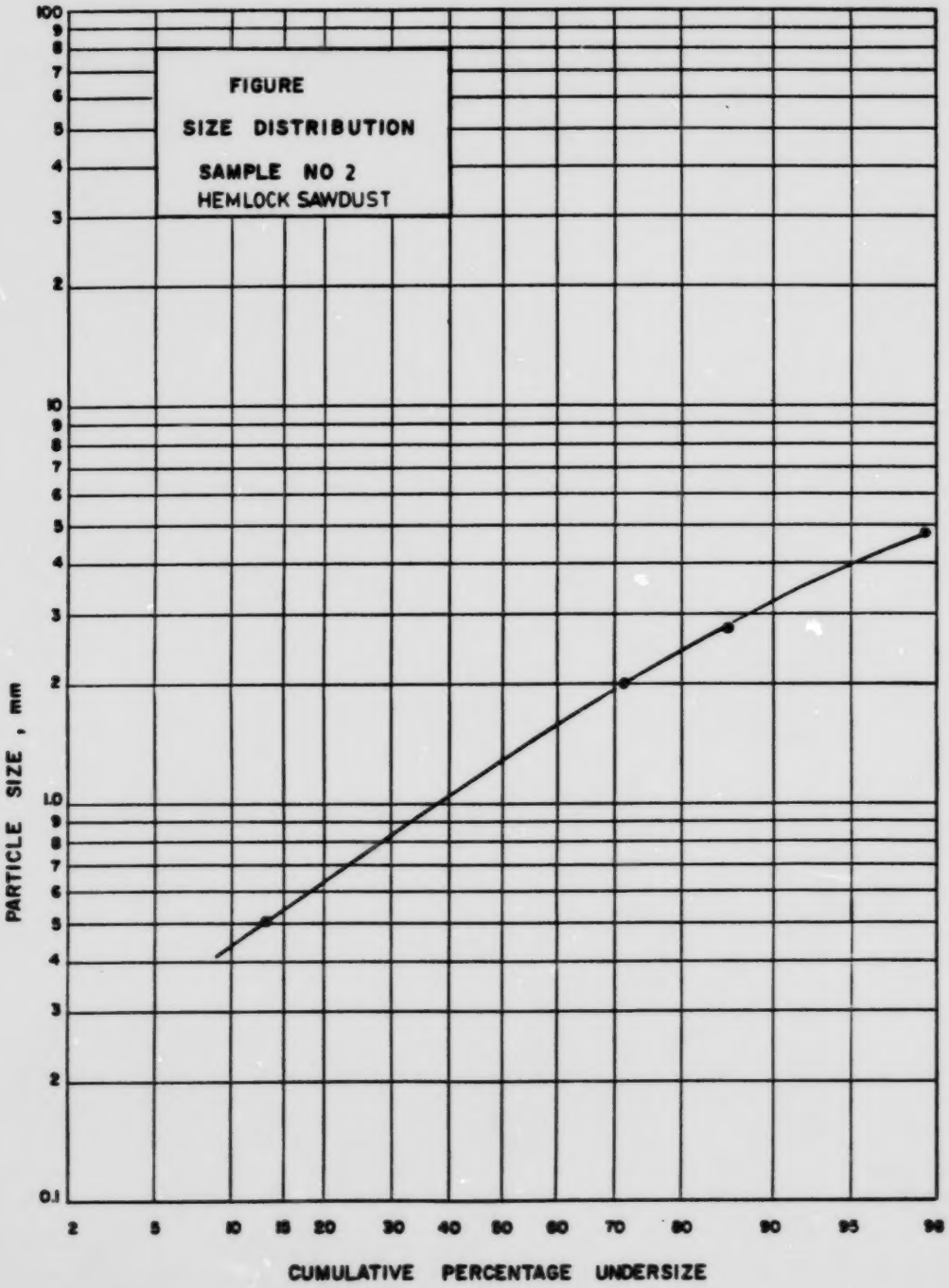


Table A7. Shear Test Results - Hemlock Chips

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
27.0	33.1		
		2.5	6.4
		4.2	19.9
		8.4	17.6
		12.6	30.0
		16.8	29.5
		24.4	29.3
		27.0	33.1
48.1	57.7		
		4.2	11.1
		8.4	14.5
		16.8	29.3
		27.0	39.4
		33.7	44.3
		39.6	50.8
		48.1	57.7
59.9	97.3		
		4.2	11.2
		8.4	24.1
		16.8	36.7
		27.0	45.2
		43.8	63.8
		56.5	75.6
		59.9	97.3
81.8	95.2		
		4.2	23.6
		12.6	49.3
		27.0	56.8
		56.5	76.1
		59.9	81.9
		73.4	96.1
		81.8	95.2
98.7	121.4		
		4.2	13.5
		12.6	51.9
		27.0	46.6
		56.5	65.5
		73.4	102.3
		90.3	112.3
		98.7	121.4
115.6	129.5		
		4.2	10.7
		12.6	24.5
		27.0	55.5
		56.5	72.4
		81.8	117.9
		107.1	126.0
		115.6	129.5

Table A8. Flow Properties - Hemlock Chips

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
27.0	33.1	77.3	49.6	1.56	63.0	53.12	6.53	1.64
48.1	57.7	118.6	62.1	1.91	56.7	53.12	8.18	2.05
59.9	97.3	172.7	111.7	1.55	63.2	53.12	14.70	3.69
81.8	95.2	216.4	125.5	1.72	59.7	53.12	16.53	4.15
98.7	121.4	248.0	133.7	1.86	57.5	53.12	17.61	4.42
115.6	129.5	276.5	138.1	2.00	55.4	53.12	18.19	4.57

SHEAR INDEX (N) = 1.69

YIELD LOCUS	PERCENT FIT
1	95.9
2	98.9
3	96.9
4	99.3
5	97.6
6	97.9

Table A9. Time Consolidation Results - Hemlock Chips

CONSOLIDATION		YIELD POINT		<----------FLOW PROPERTIES---------->				
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS INST	MAJ PRINC CONSOL'N STRESS TIME	UNCONFIN YIELD STRESS	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	DEG	DEG	G/SQ CM
CONSOLIDATION PERIOD 16 HRS									
81.8	106.7	81.8	109.2	216.5	233.8	155.9	65.5	53.2	20.52
CONSOLIDATION PERIOD 65 HRS									
115.6	146.6	115.6	150.4	276.5	322.5	207.9	64.2	53.2	27.36

SHEAR INDEX (N) = 1.69

COHESION/ TENSILE STRENGTH = 3.98

Figure A5. Material & Hopper Flow Factors - Hemlock Chips

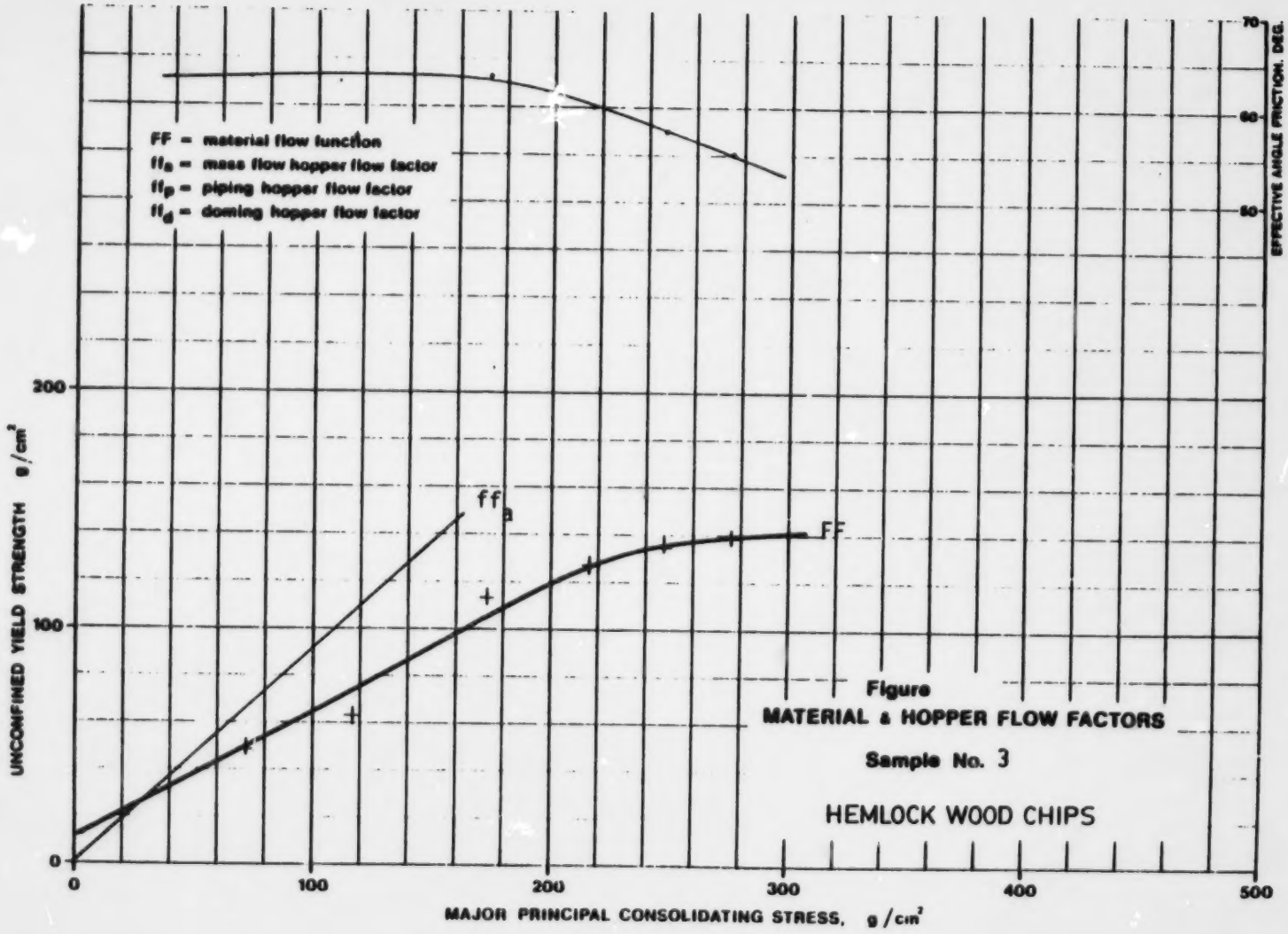


Figure A6. Particle Size Distribution - Hemlock Chips

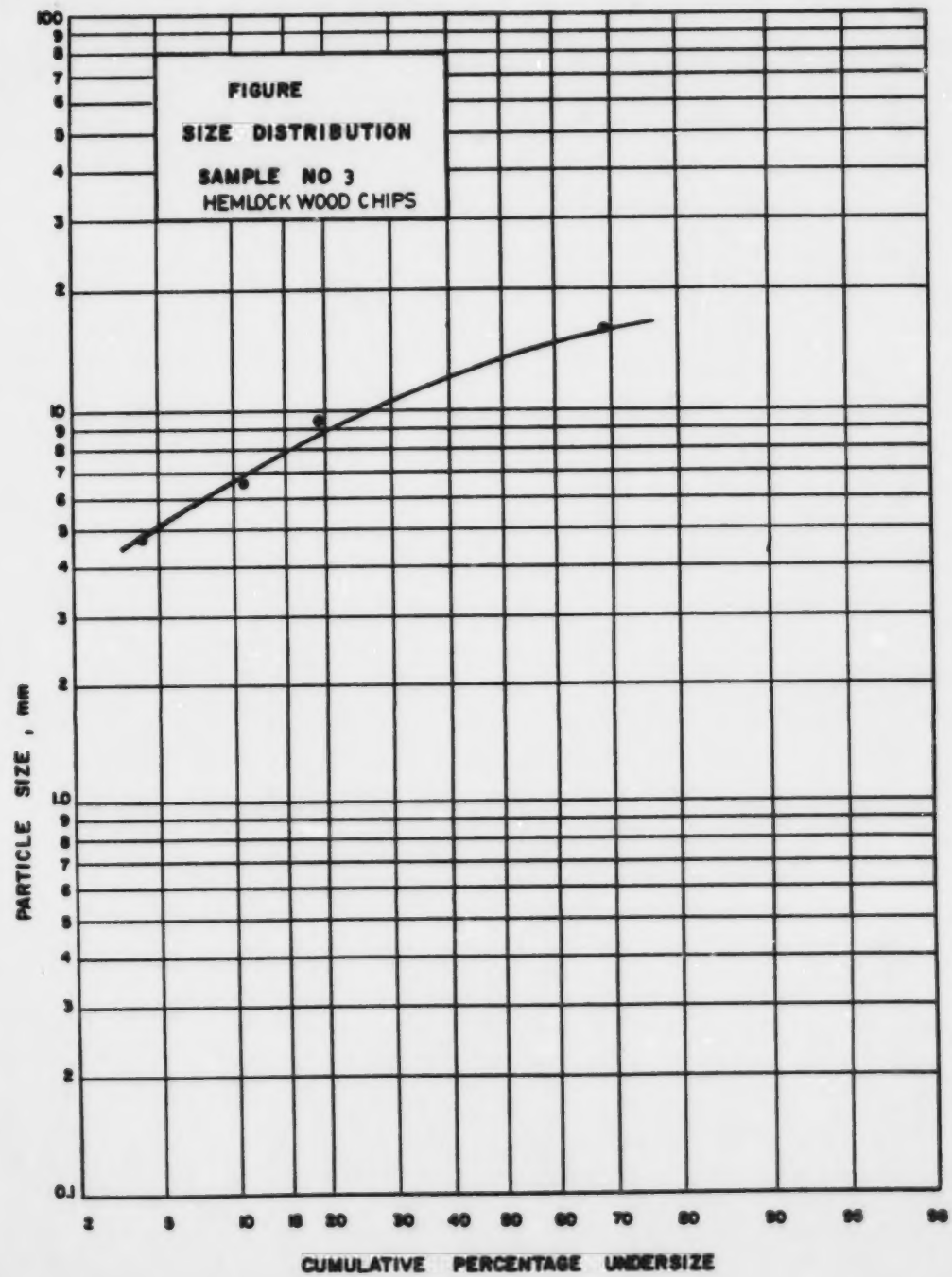


Table A10. Shear Test Results - Cedar Hogfuel

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	16.5		
		1.5	4.7
		2.9	5.5
		4.3	7.7
		6.2	9.6
		11.8	15.5
		13.2	14.5
		14.6	16.5
24.3	35.3		
		1.5	4.9
		2.9	6.5
		4.3	8.2
		9.0	14.9
		14.6	21.7
		21.0	27.3
		24.3	35.3
45.0	66.6		
		1.5	7.1
		2.9	11.1
		4.3	13.9
		9.0	22.5
		18.2	29.6
		33.9	41.2
		45.0	66.6
60.3	61.2		
		1.5	5.8
		2.9	9.3
		4.3	14.5
		9.0	18.1
		24.3	38.6
		45.0	50.0
		60.3	61.2
85.6	102.3		
		1.5	7.6
		4.3	10.4
		24.3	37.6
		45.0	68.7
		60.3	78.0
		70.4	79.1
		85.6	102.3

Table A11. Flow Properties - Cedar Hogfuel

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	16.5	40.3	8.2	4.93	53.1	61.21	.94	.29
24.3	35.3	76.3	20.9	3.66	57.0	61.21	2.39	.74
45.0	66.6	144.1	40.9	3.52	57.5	61.21	4.69	1.45
60.3	61.2	152.1	24.5	6.21	50.2	61.21	2.81	.87
85.6	102.3	234.7	47.0	4.99	52.9	61.21	5.39	1.67

SHEAR INDEX (N) = 1.36

YIELD LOCUS	PERCENT FIT
1	99.3
2	99.1
3	98.0
4	99.1
5	99.4

Table A12. Time Consolidation Results - Cedar Hogfuel

CONSOLIDATION NORMAL STRESS	CONSOLIDATION SHEAR STRESS	YIELD POINT NORMAL STRESS	YIELD POINT SHEAR STRESS	FLOW PROPERTIES MAJ PRINC CONSOL'N STRESS INST	FLOW PROPERTIES MAJ PRINC CONSOL'N STRESS TIME	FLOW PROPERTIES UNCONFIN YIELD STRESS	FLOW PROPERTIES EFFECT FRIC ANGLE	FLOW PROPERTIES INTERNAL FRIC ANG AT FREE SURFACE	FLOW PROPERTIES COHESION
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		G/SQ CM	DEG	DEG	G/SQ CM
CONSOLIDATION PERIOD 1 HR									
14.6	16.5	14.6	19.6	40.2	46.8	13.2	58.1	61.7	1.48
CONSOLIDATION PERIOD 16 HRS									
45.0	58.7	45.0	62.7	143.8	150.2	46.1	59.4	61.7	5.20
CONSOLIDATION PERIOD 90 HRS									
24.3	31.4	24.3	38.9	76.4	94.9	39.8	64.2	61.7	4.48

SHEAR INDEX (N) = 1.36

COHESION/ TENSILE STRENGTH = 3.30

Figure A7. Material & Hopper Flow Factors - Cedar Hogfuel

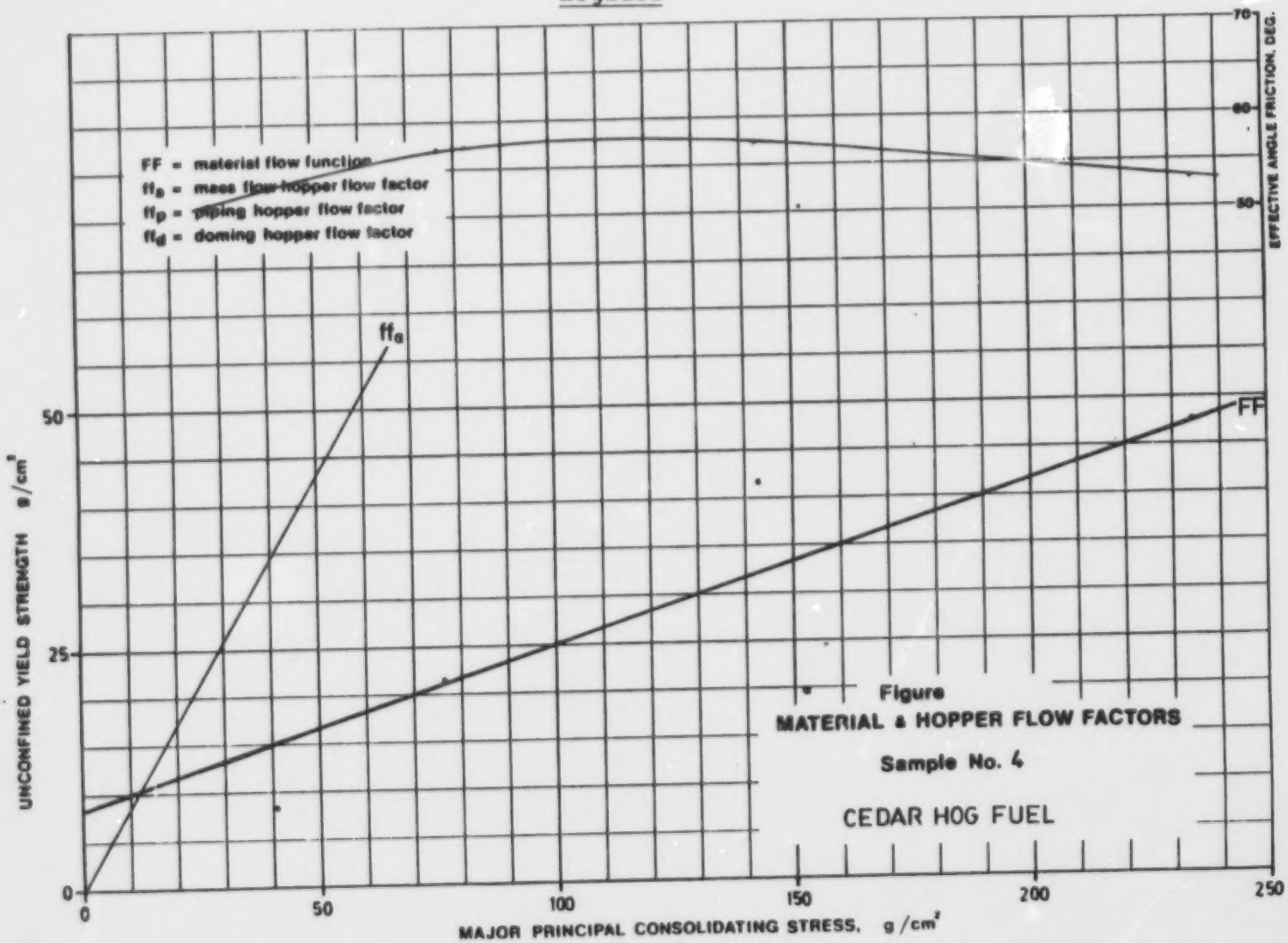


Figure A8. Particle Size Distribution - Cedar Hogfuel

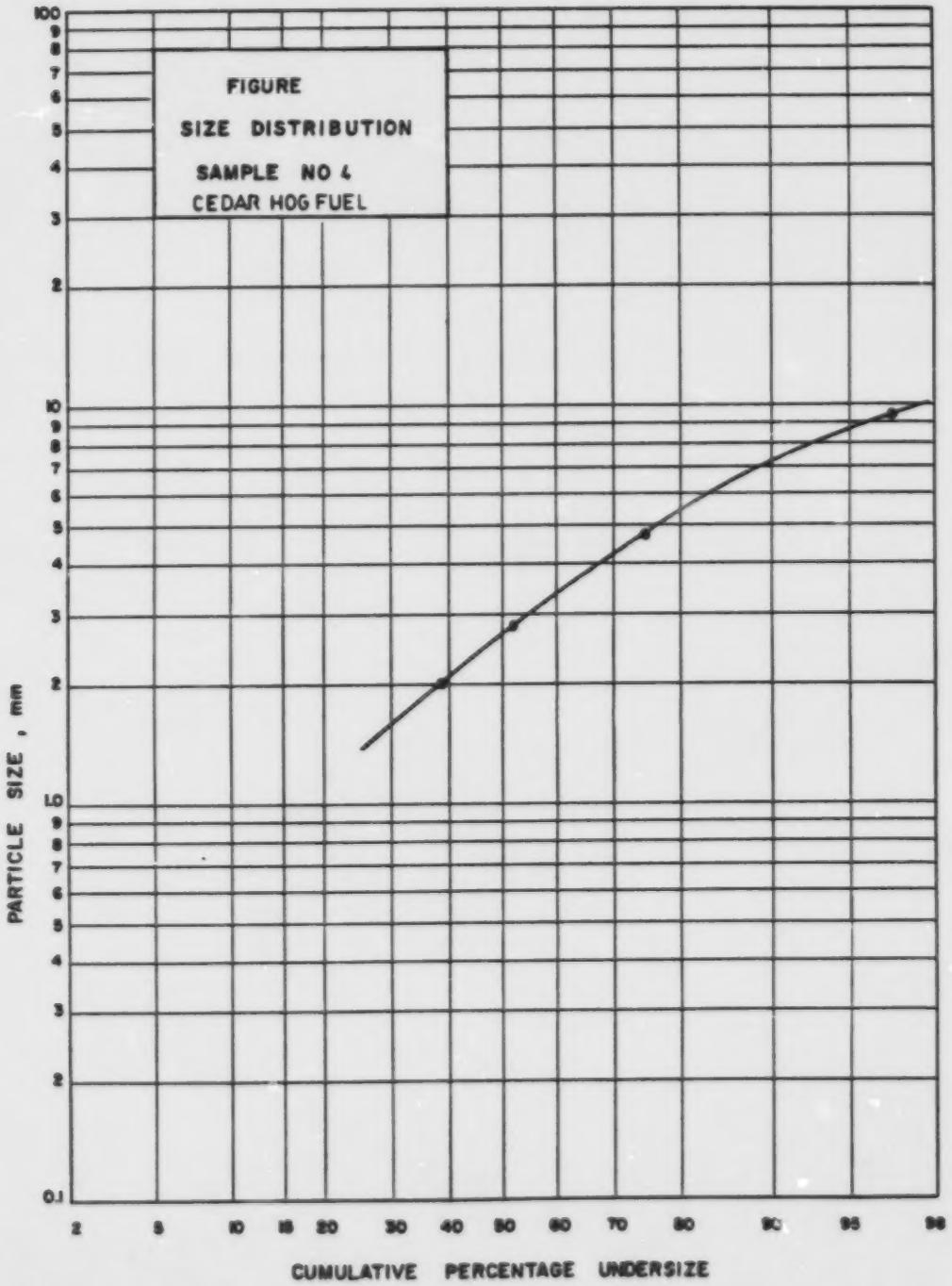


Table A13. Shear Test Results - Cedar Sawdust

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	14.8		
		1.5	4.1
		2.9	6.3
		4.3	6.2
		6.2	7.3
		11.8	12.7
		13.2	13.8
		14.6	14.8
24.3	23.5		
		1.5	4.4
		2.9	6.7
		4.3	9.4
		9.0	15.7
		14.6	18.5
		21.0	22.5
		24.3	23.5
45.0	43.0		
		1.5	3.4
		2.9	5.2
		4.3	7.6
		9.0	15.0
		18.2	24.5
		33.9	37.7
		45.0	43.0
60.3	58.9		
		1.5	3.0
		2.9	5.5
		4.3	7.0
		9.0	10.0
		24.3	28.1
		45.0	43.3
		60.3	58.9
85.6	98.2		
		1.5	9.7
		4.3	22.6
		24.3	42.0
		45.0	64.4
		60.3	72.0
		70.4	92.2
		85.6	98.2

Table A14. Flow Properties - Cedar Sawdust

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	14.8	33.9	9.6	3.51	49.7	55.26	1.31	.44
24.3	23.5	58.0	17.7	3.29	50.8	55.26	2.41	.81
45.0	43.0	99.9	25.5	3.91	47.9	55.26	3.48	1.17
60.3	59.3	126.1	27.3	4.61	45.3	55.26	3.73	1.26
85.6	98.2	223.6	82.5	2.71	54.2	55.26	11.25	3.79

SHEAR INDEX (N) = 1.46

YIELD LOCUS	PERCENT FIT
1	99.4
2	99.2
3	99.2
4	98.1
5	99.5

Table A15. Time Consolidation Results - Cedar Sawdust

CONSOLIDATION NORMAL STRESS	CONSOLIDATION SHEAR STRESS	YIELD POINT NORMAL STRESS	YIELD POINT SHEAR STRESS	FLOW PROPERTIES MAJ PRINC CONSOL'N STRESS INST	FLOW PROPERTIES MAJ PRINC CONSOL'N STRESS TIME	FLOW PROPERTIES UNCONFIN YIELD STRESS	FLOW PROPERTIES EFFECT FRIC ANGLE	FLOW PROPERTIES INTERNAL FRIC ANG AT FREE SURFACE	FLOW PROPERTIES COHESION
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		G/SQ CM	DEG	DEG	G/SQ CM
CONSOLIDATION PERIOD 1 HR									
24.3	24.3	24.3	25.1	8.0	57.9	17.1	50.8	55.6	2.31
CONSOLIDATION PERIOD 16 HRS									
60.3	60.0	60.3	65.7	125.9	150.6	49.8	52.7	55.6	6.71
CONSOLIDATION PERIOD 24 HRS									
85.6	101.0	85.6	109.6	223.4	249.0	112.8	58.9	55.6	15.19

SHEAR INDEX (N) = 1.46

COHESION/ TENSILE STRENGTH = 3.00

Figure A9. Material & Hopper Flow Factors - Cedar Sawdust

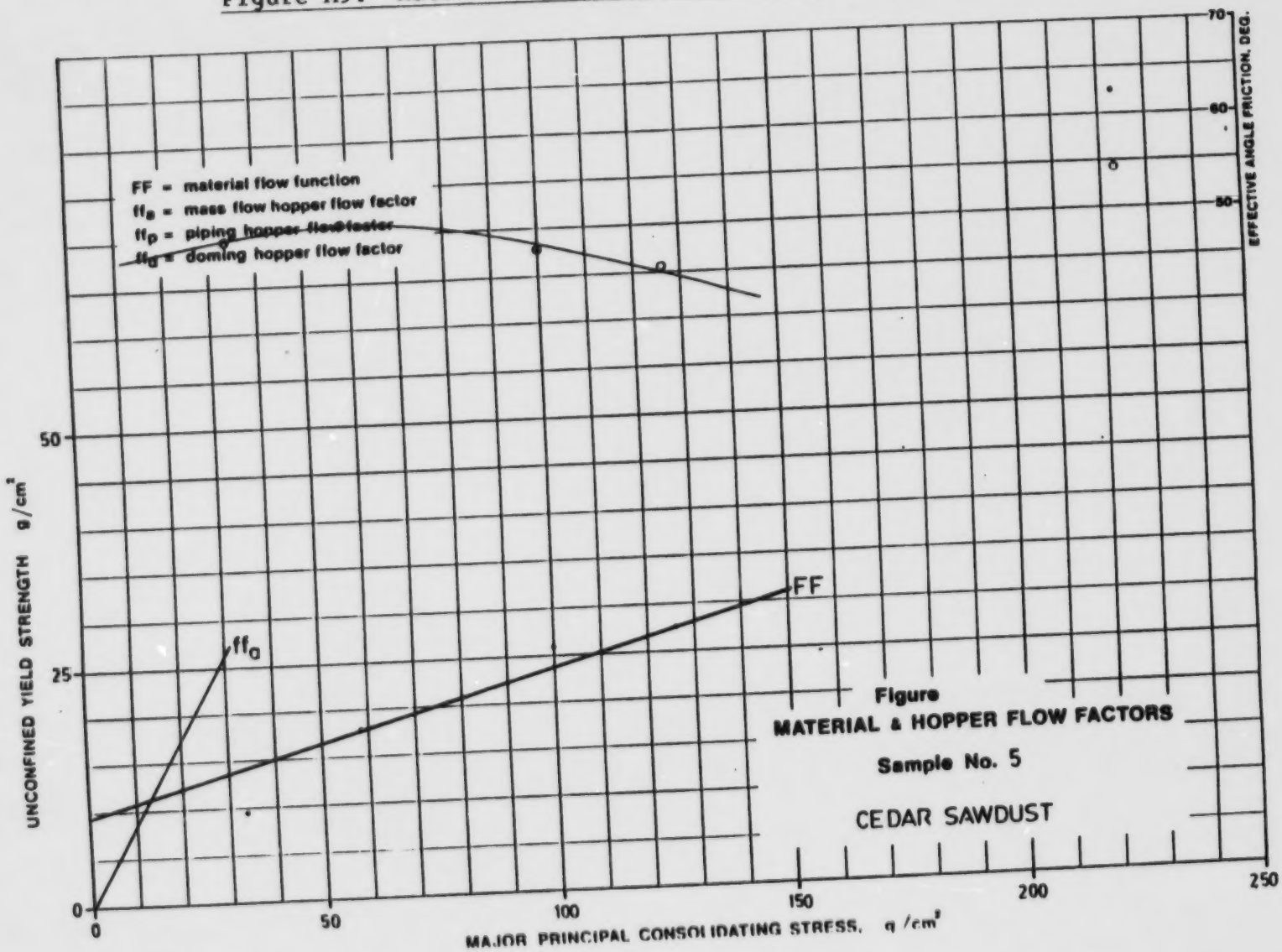


Figure A10. Particle Size Distribution - Cedar Sawdust

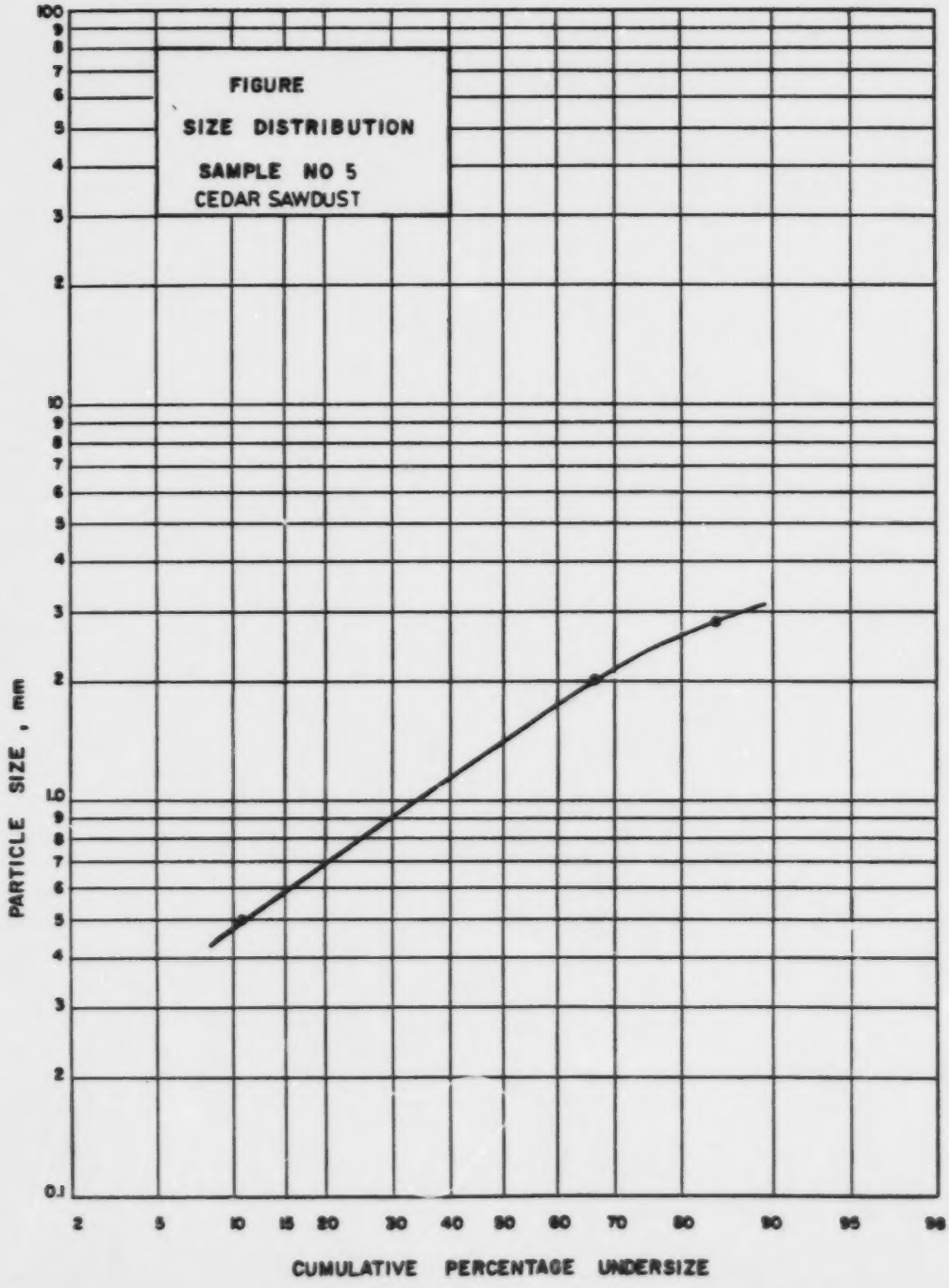


Table A16. Shear Test Results - Cedar Chips

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
27.0	37.6		
		2.5	9.2
		4.2	23.0
		8.4	25.3
		12.6	28.1
		16.8	31.3
		24.4	36.9
		27.0	37.6
48.1	60.7		
		4.2	9.0
		8.4	28.3
		16.8	37.3
		27.0	45.7
		33.7	52.7
		39.6	55.5
		48.1	60.7
59.9	78.4		
		4.2	12.5
		8.4	20.5
		16.8	32.5
		27.0	48.0
		43.8	62.2
		56.5	73.6
		59.9	78.4
59.9	78.4		
		4.2	12.5
		8.4	20.5
		16.8	32.5
		27.0	48.0
		43.8	62.2
		56.5	73.6
		59.9	78.4
98.7	122.3		
		4.2	17.9
		12.6	34.7
		27.0	80.6
		56.5	85.6
		73.4	95.7
		90.3	107.6
		98.7	122.3
115.6	140.4		
		4.2	12.9
		12.6	36.2
		27.0	61.8
		56.5	103.6
		81.8	112.3
		107.1	136.3
		115.6	140.4

Table A17. Flow Properties - Cedar Chips

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
27.0	37.6	83.8	70.4	1.19	71.4	48.86	9.95	2.35
48.1	60.7	127.7	91.6	1.39	63.8	48.86	12.95	3.06
59.9	78.4	151.9	103.1	1.47	61.5	48.86	14.59	3.45
59.9	78.4	151.9	103.1	1.47	61.5	48.86	14.59	3.45
98.7	122.3	246.3	164.0	1.50	60.7	48.86	23.20	5.49
115.6	140.4	287.2	190.1	1.51	60.5	48.86	26.90	6.36

SHEAR INDEX (N) = 1.83

YIELD LOCUS	PERCENT FIT
1	98.3
2	98.5
3	98.2
4	98.2
5	98.1
6	98.3

Figure A11. Material & Hopper Flow Factors - Cedar Chips

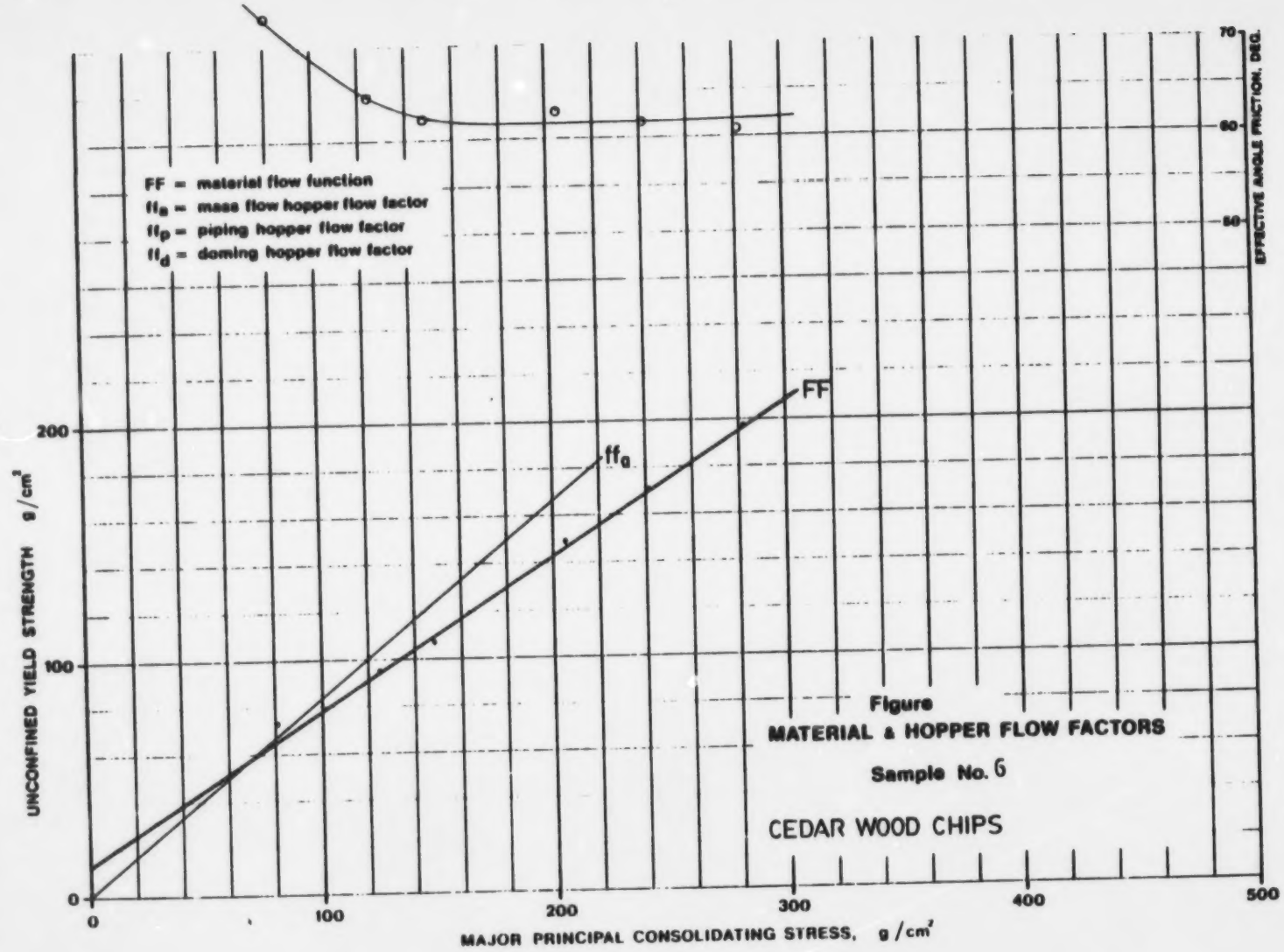


Figure A12. Particle Size Distribution - Cedar Chips

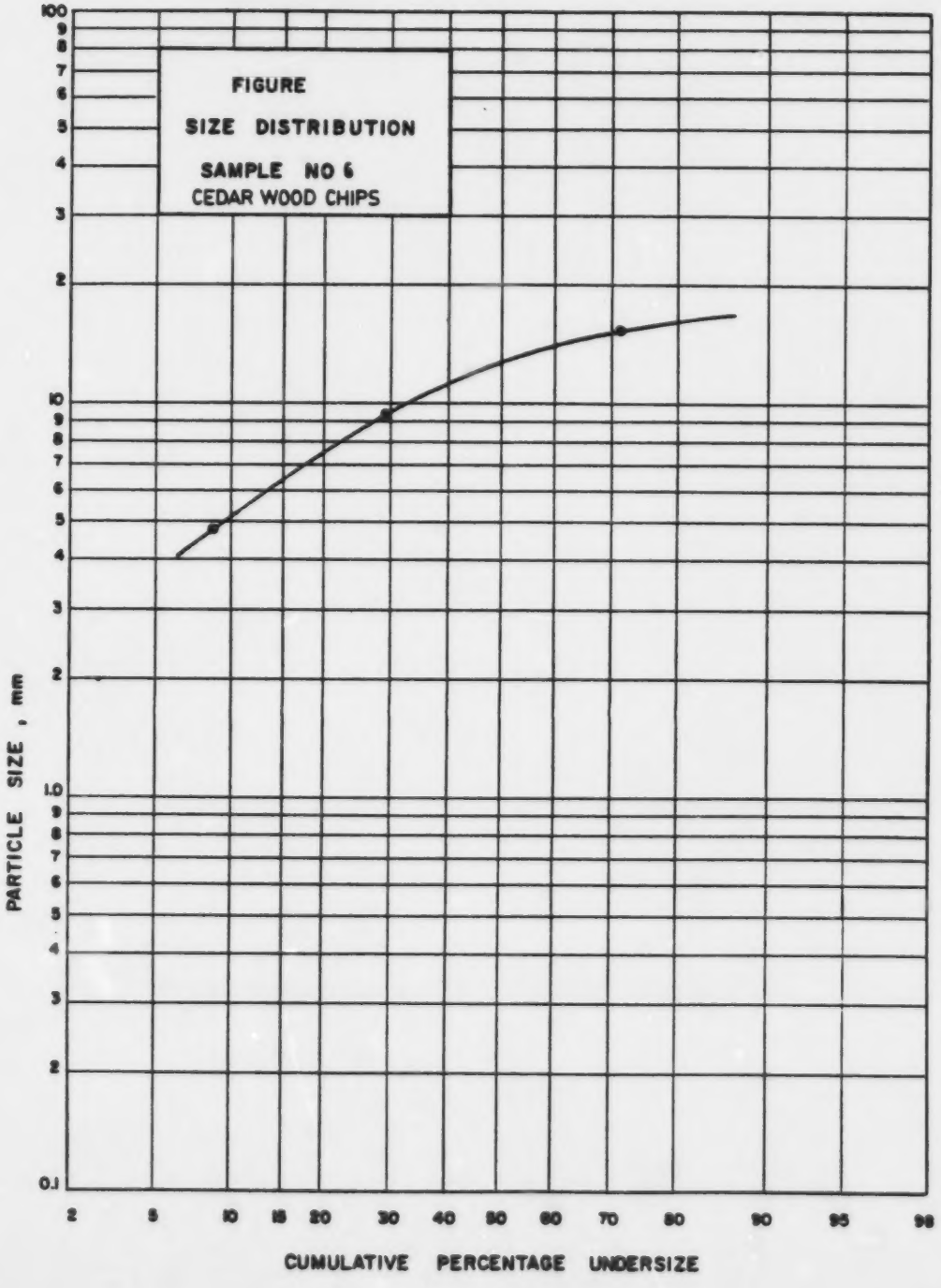


Table A18. Shear Test Results - Coarse Shavings

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	18.4		
		1.5	3.7
		2.9	7.0
		4.3	8.1
		6.2	11.3
		11.8	15.8
		13.2	16.4
		14.6	18.4
24.3	24.7		
		1.5	5.5
		2.9	8.8
		4.3	15.2
		9.0	17.2
		14.6	22.4
		21.0	22.5
		24.3	24.7
45.0	45.8		
		1.5	4.0
		2.9	7.5
		4.3	10.2
		9.0	15.6
		18.2	27.1
		33.9	41.7
		45.0	45.8
60.3	76.4		
		1.5	4.6
		2.9	6.4
		4.3	17.2
		9.0	26.7
		24.3	39.1
		45.0	67.2
		60.3	76.4
85.6	93.3		
		1.5	5.5
		4.3	11.7
		24.3	48.8
		45.0	81.3
		60.3	96.0
		70.4	96.0
		85.6	93.3
115.9	139.4		
		1.5	5.8
		4.3	6.8
		24.3	46.9
		45.0	70.9
		70.4	104.2
		85.6	125.5
		115.9	139.4

Table A19. Flow Properties - Coarse Shavings

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	18.4	39.9	18.7	2.13	57.8	56.19	2.36	.64
24.3	24.7	61.8	25.8	2.40	55.1	56.19	3.25	.89
45.0	45.8	104.0	36.2	2.87	51.3	56.19	4.56	1.25
60.3	76.4	164.5	77.0	2.14	57.8	56.19	9.70	2.65
85.6	93.3	234.5	110.3	2.12	57.9	56.19	13.90	3.80
115.9	139.4	303.9	133.3	2.28	56.3	56.19	16.79	4.59

SHEAR INDEX (N) = 1.57

YIELD LOCUS	PERCENT FIT
1	99.6
2	96.9
3	99.1
4	98.0
5	97.8
6	98.0

Table A20. Time Consolidation Results - Coarse Shavings

CONSOLIDATION		YIELD POINT		<----------FLOW PROPERTIES---------->					
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS INST	MAJ PRINC CONSOL'N STRESS TIME	UNCONFIN YIELD STRESS	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		G/SQ CM	DEG	DEG	G/SQ CM
CONSOLIDATION PERIOD 1 HR									
60.3	62.0	60.3	64.4	164.2	144.7	55.5	53.3	56.0	7.02
CONSOLIDATION PERIOD 23 HRS									
115.9	141.8	115.9	165.6	303.3	366.3	224.3	65.6	56.0	28.38
CONSOLIDATION PERIOD 64 HRS									
45.0	45.9	45.0	48.0	103.9	107.8	41.3	53.2	56.0	5.22

SHEAR INDEX (N) = 1.57

COHESION/ TENSILE STRENGTH = 3.66

Figure A13. Material & Hopper Flow Factors - Coarse Shavings

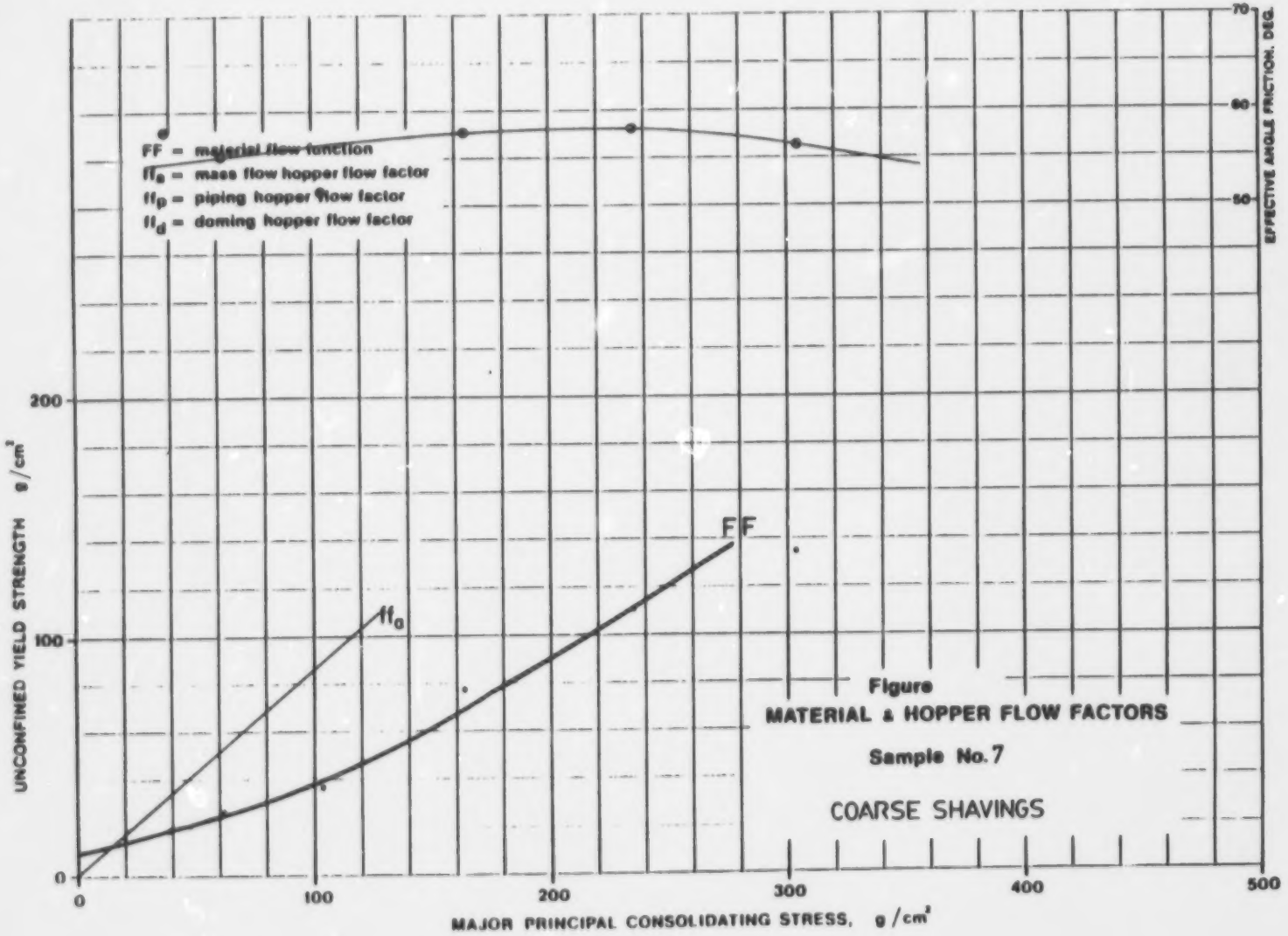


Figure A14. Particle Size Distribution - Coarse Shavings

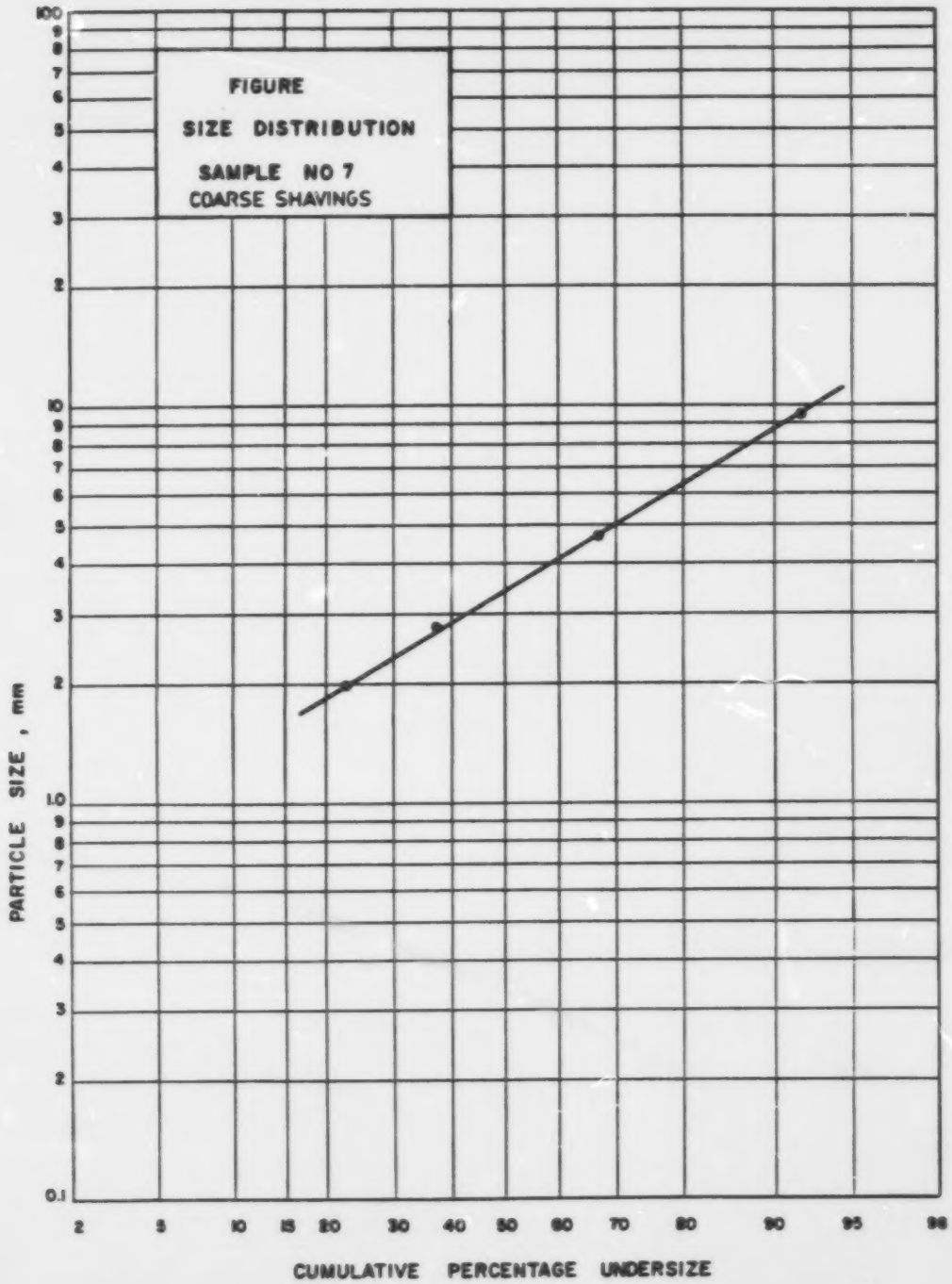


Table A21. Shear Test Results - Fine Shavings

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
21.9	72.8		
		2.3	16.0
		4.4	23.6
		6.5	32.4
		9.3	44.0
		17.7	62.8
		19.8	64.8
		21.9	72.8
36.5	135.2		
		2.3	16.4
		4.4	21.2
		6.5	29.6
		13.5	59.6
		21.9	102.8
		31.5	120.0
		36.5	135.2
67.5	230.4		
		2.3	19.6
		4.4	24.0
		6.5	48.4
		13.5	85.2
		27.3	113.2
		50.9	189.2
		67.5	230.4
90.5	302.0		
		2.3	24.8
		4.4	35.6
		6.5	49.2
		13.5	82.0
		36.5	172.0
		67.5	240.0
		90.5	302.0
128.4	497.6		
		2.3	30.4
		6.5	52.4
		36.5	204.8
		67.5	320.4
		90.5	340.4
		105.6	461.6
		128.4	497.6

Table A22. Flow Properties - Fine Shavings

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
21.9	72.8	299.7	78.4	3.82	76.4	79.29	3.25	.36
36.5	135.2	577.5	180.3	3.20	77.6	79.29	7.48	.82
67.5	230.4	953.0	258.9	3.68	76.7	79.29	10.75	1.18
90.5	302.0	******	329.6	3.79	76.5	79.29	13.68	1.51
128.4	497.6	******	768.9	2.89	78.3	79.29	31.91	3.52

SHEAR INDEX (N) = 1.32

YIELD LOCUS	PERCENT FIT
1	99.6
2	99.1
3	99.6
4	99.8
5	99.3

Figure A15. Material & Hopper Flow Factors - Fine Shavings

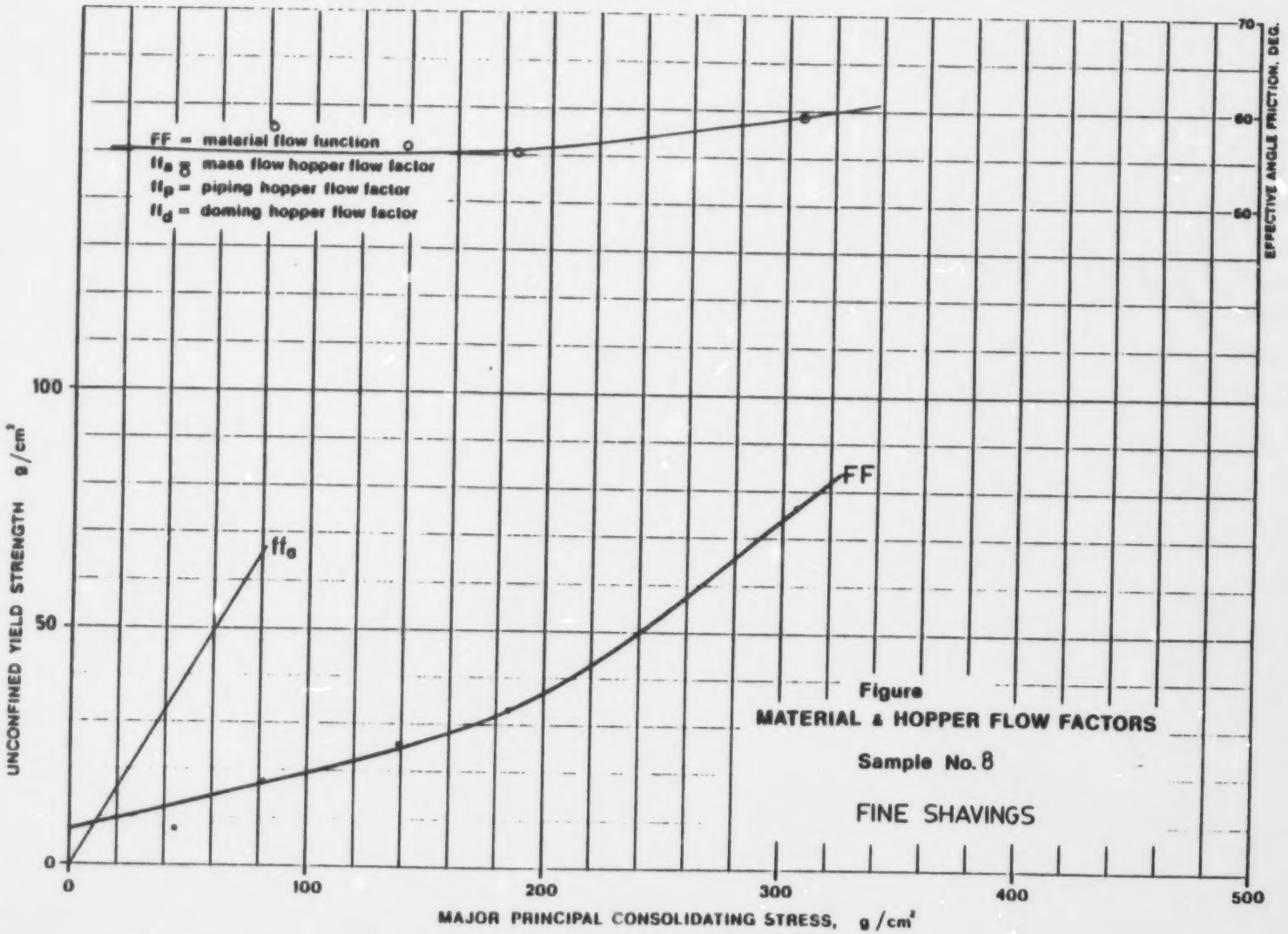


Figure A16. Particle Size Distribution - Fine Shavings

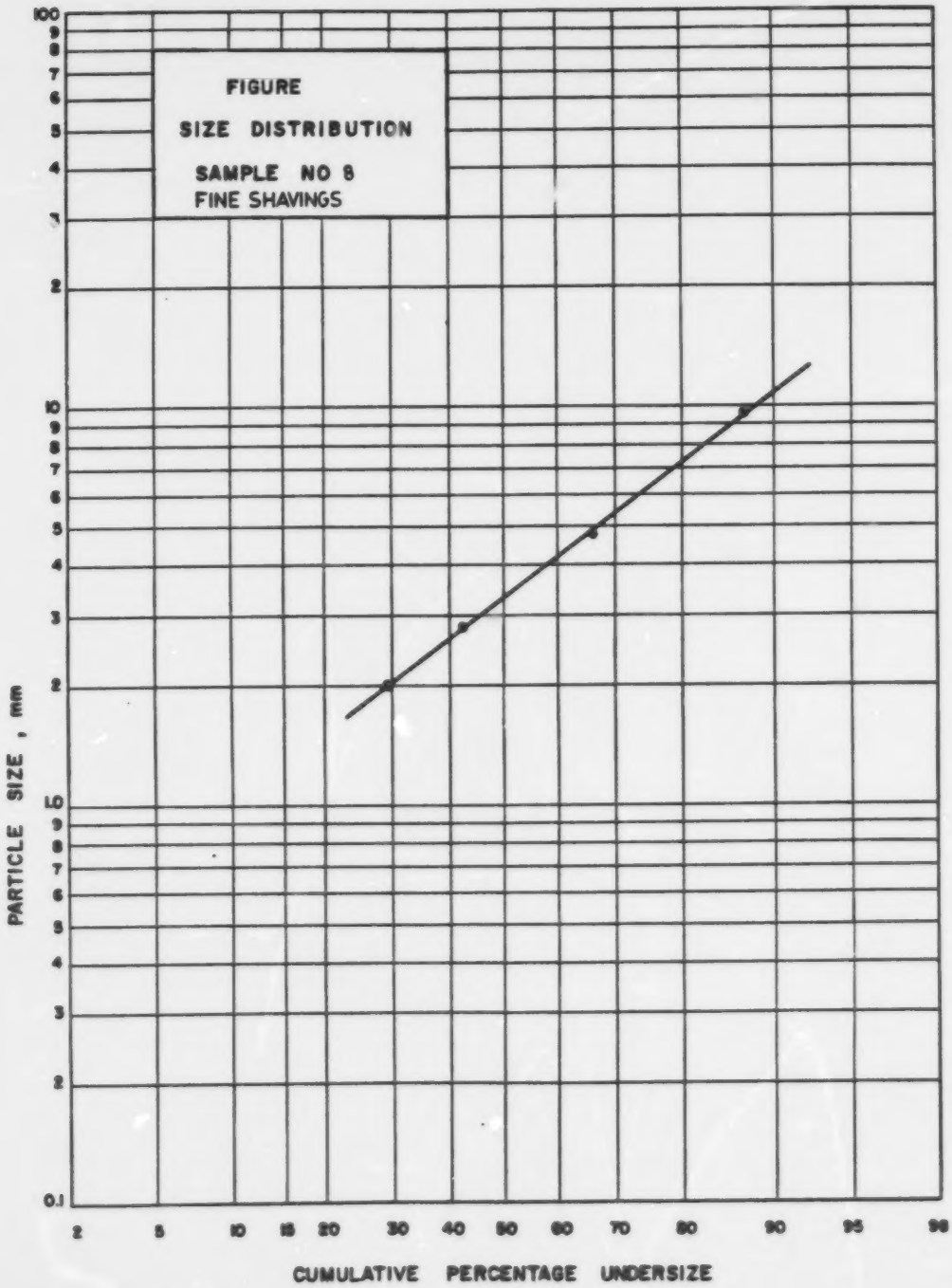


Table A23. Shear Test Results - Sawdust

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	18.4		
		1.5	2.8
		2.9	6.9
		4.3	7.9
		6.2	8.5
		11.8	14.2
		13.2	17.9
		14.6	18.4
24.3	28.1		
		1.5	5.2
		2.9	8.4
		4.3	8.2
		9.0	12.4
		14.6	20.5
		21.0	23.5
		24.3	28.1
45.0	55.4		
		1.5	5.7
		2.9	5.8
		4.3	8.3
		9.0	25.4
		18.2	40.0
		33.9	43.3
		45.0	55.4
60.3	74.3		
		1.5	8.1
		2.9	8.2
		4.3	11.5
		9.0	17.7
		24.3	42.8
		45.0	60.8
		60.3	74.3
85.6	99.3		
		1.5	7.2
		4.3	11.9
		24.3	43.6
		45.0	70.0
		60.3	86.2
		70.4	82.1
		85.6	99.3

Table A24. Flow Properties - Sawdust

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	18.4	40.8	13.4	3.04	55.6	59.25	1.60	.46
24.3	28.1	62.9	17.8	3.54	53.1	59.25	2.12	.62
45.0	55.4	129.9	45.5	2.85	56.7	59.25	5.42	1.58
60.3	74.3	167.9	55.0	3.05	55.5	59.25	6.55	1.91
85.6	99.3	231.6	71.6	3.23	54.6	59.25	8.53	2.49

SHEAR INDEX (N) = 1.45

YIELD LOCUS	PERCENT FIT
1	98.8
2	99.4
3	96.7
4	99.3
5	99.3

Figure A17. Material & Hopper Flow Factors - Sawdust

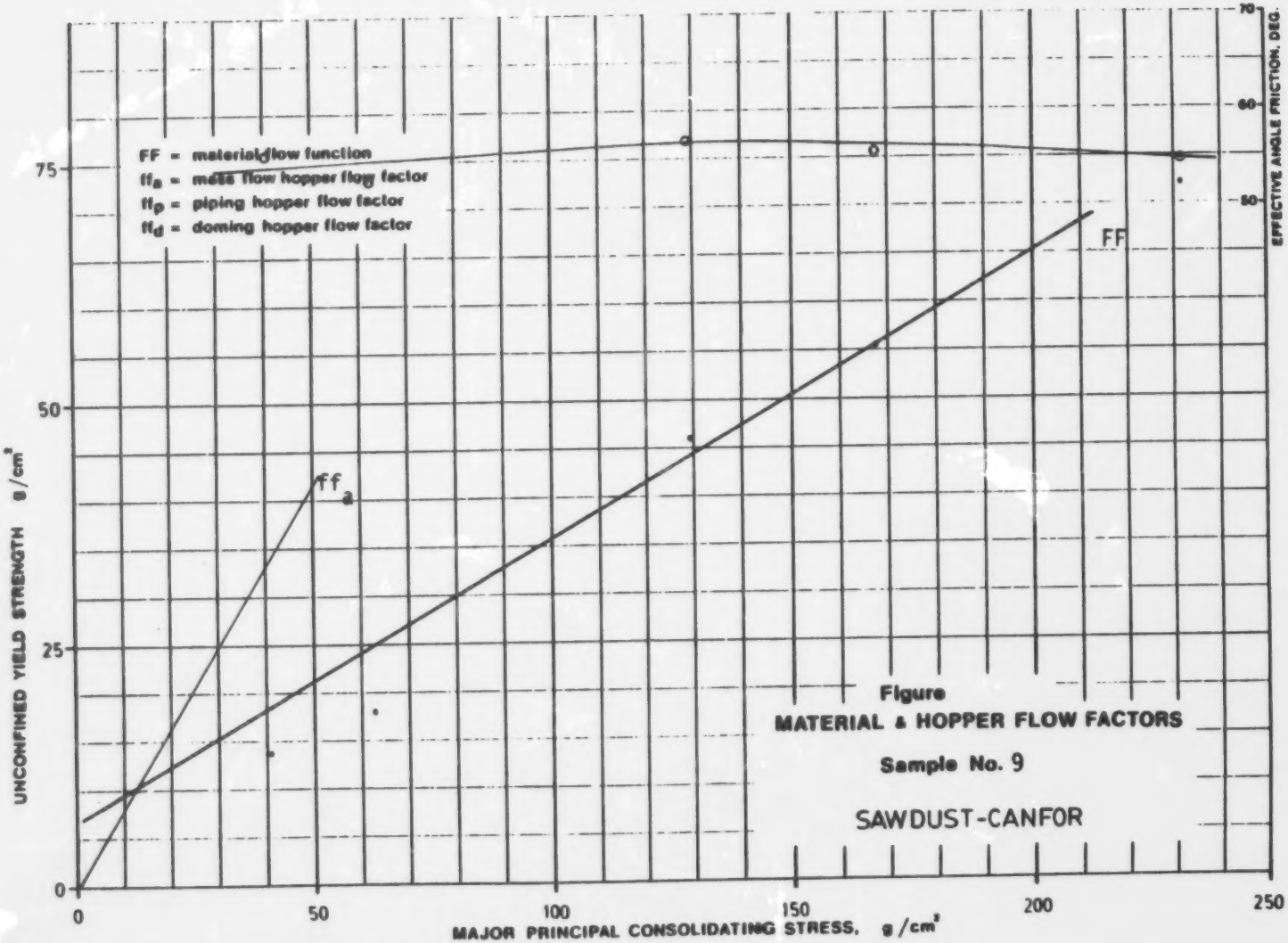


Figure A18. Particle Size Distribution - Sawdust

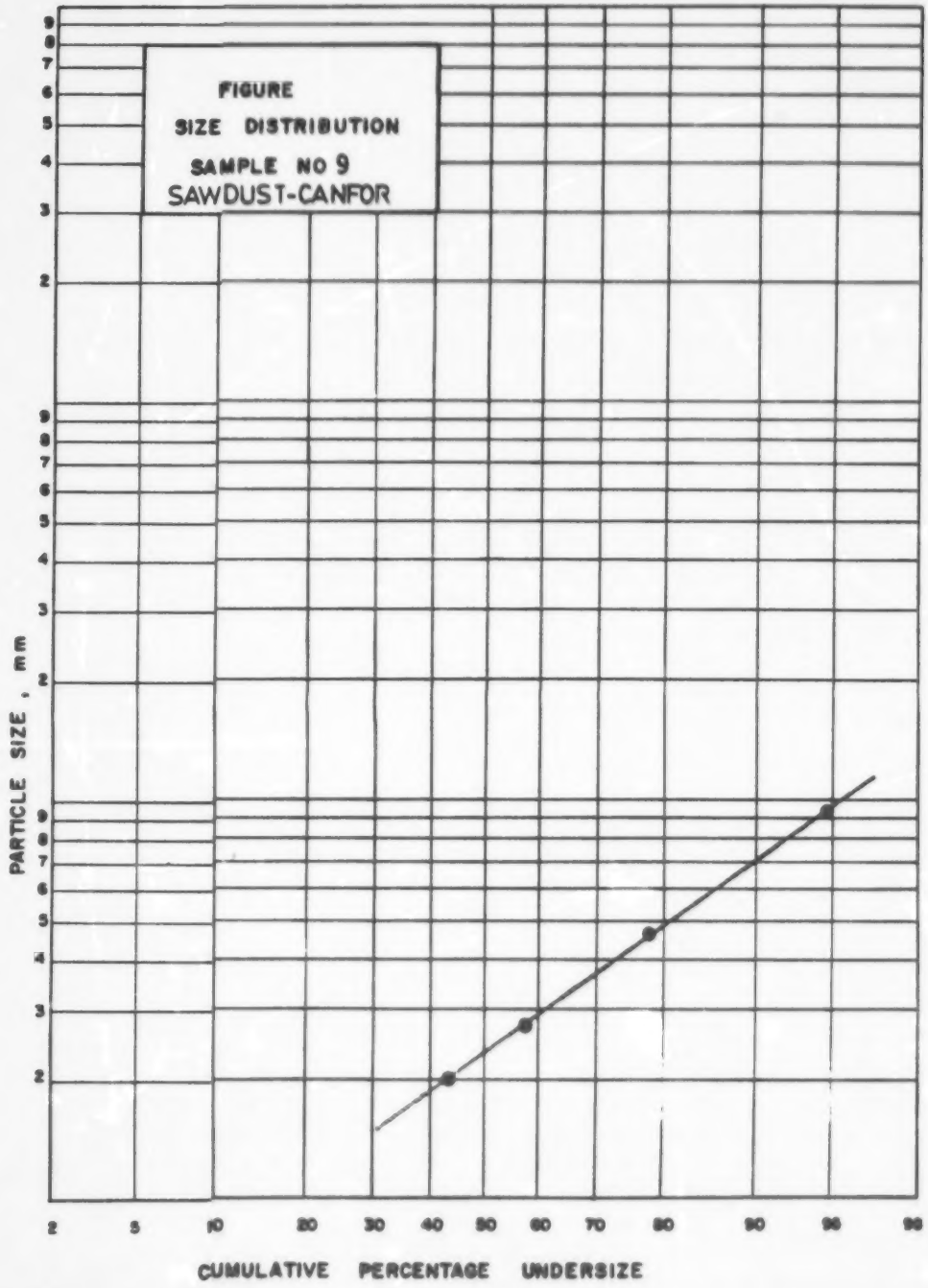


Table A25. Shear Test Results - Peat Moss

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	15.2		
		1.5	4.2
		2.9	5.6
		4.3	7.0
		6.2	9.1
		11.8	13.7
		13.2	13.9
		14.6	15.2
24.3	24.2		
		1.5	3.2
		2.9	7.9
		4.3	9.4
		9.0	15.1
		14.6	17.8
		21.0	26.6
		24.3	24.2
45.0	49.3		
		1.5	5.9
		2.9	9.2
		4.3	9.8
		9.0	15.8
		18.2	28.4
		33.9	42.8
		45.0	49.3
60.3	58.5		
		1.5	6.6
		2.9	7.0
		4.3	9.8
		9.0	22.8
		24.3	34.0
		45.0	45.9
		60.3	58.5
85.6	87.7		
		1.5	5.6
		4.3	13.9
		24.3	53.5
		45.0	72.8
		60.3	78.2
		70.4	81.0
		85.6	87.7
115.9	133.0		
		1.5	4.1
		4.3	8.6
		24.3	53.1
		45.0	68.7
		70.4	94.1
		85.6	110.5
		115.9	133.0

Table A26. Flow Properties - Peat Moss

TABLE 2.- FLOW PROPERTIES OF MATERIAL

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	15.2	34.8	12.0	2.89	51.7	55.10	1.61	.50
24.3	24.2	59.3	21.6	2.75	52.6	55.10	2.89	.90
45.0	49.3	110.1	40.3	2.73	52.8	55.10	5.41	1.69
60.3	58.5	133.0	38.8	3.43	48.5	55.10	5.21	1.63
85.6	87.7	214.8	82.5	2.60	53.8	55.10	11.07	3.46
115.9	133.0	290.5	111.4	2.61	53.7	55.10	14.95	4.67

SHEAR INDEX (N) = 1.51

YIELD LOCUS	PERCENT FIT
1	99.9
2	98.7
3	99.4
4	99.2
5	98.5
6	98.7

Figure A19. Material & Hopper Flow Factors - Peat Moss

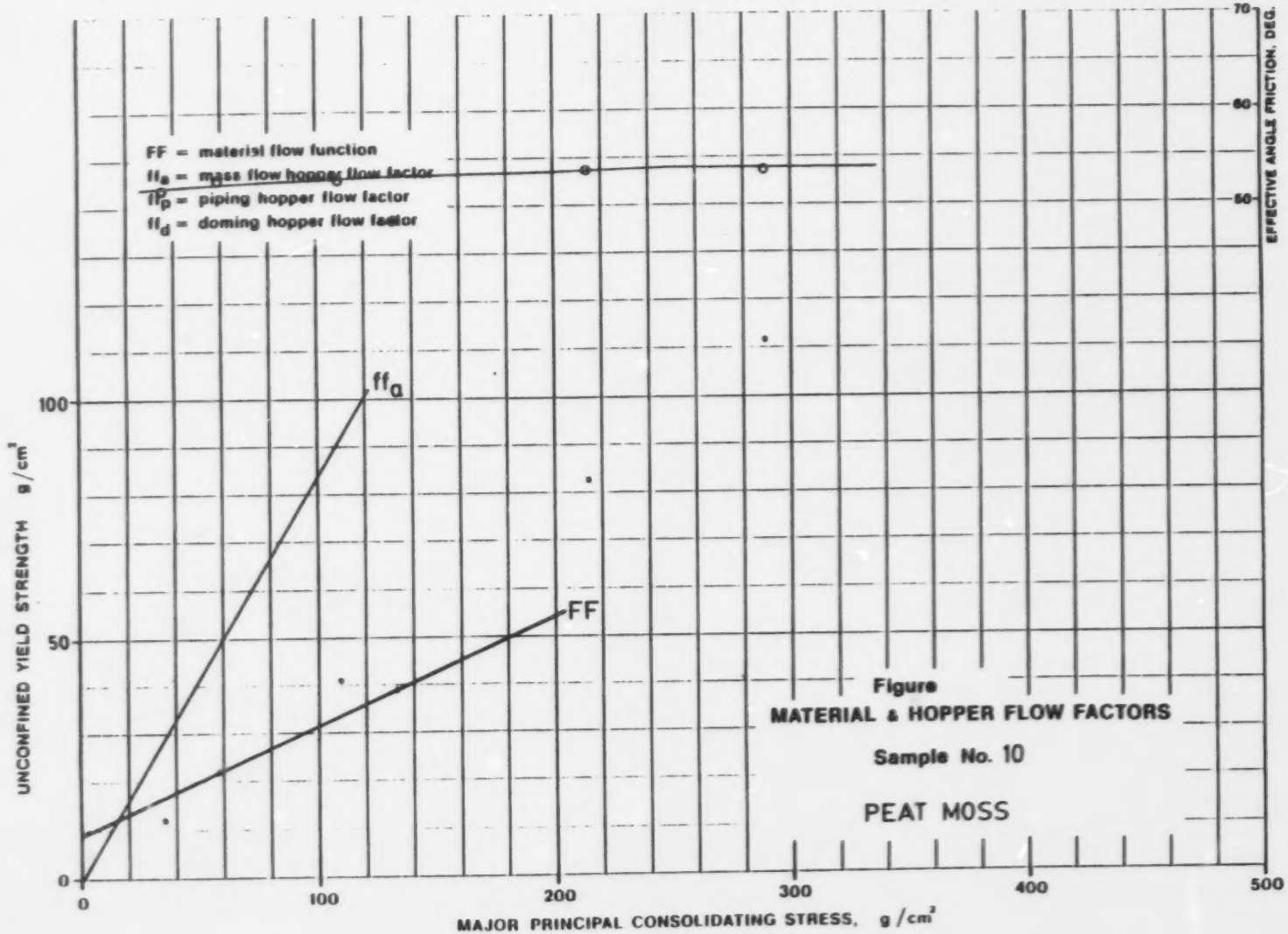


Figure A20. Particle Size Distribution - Peat Moss

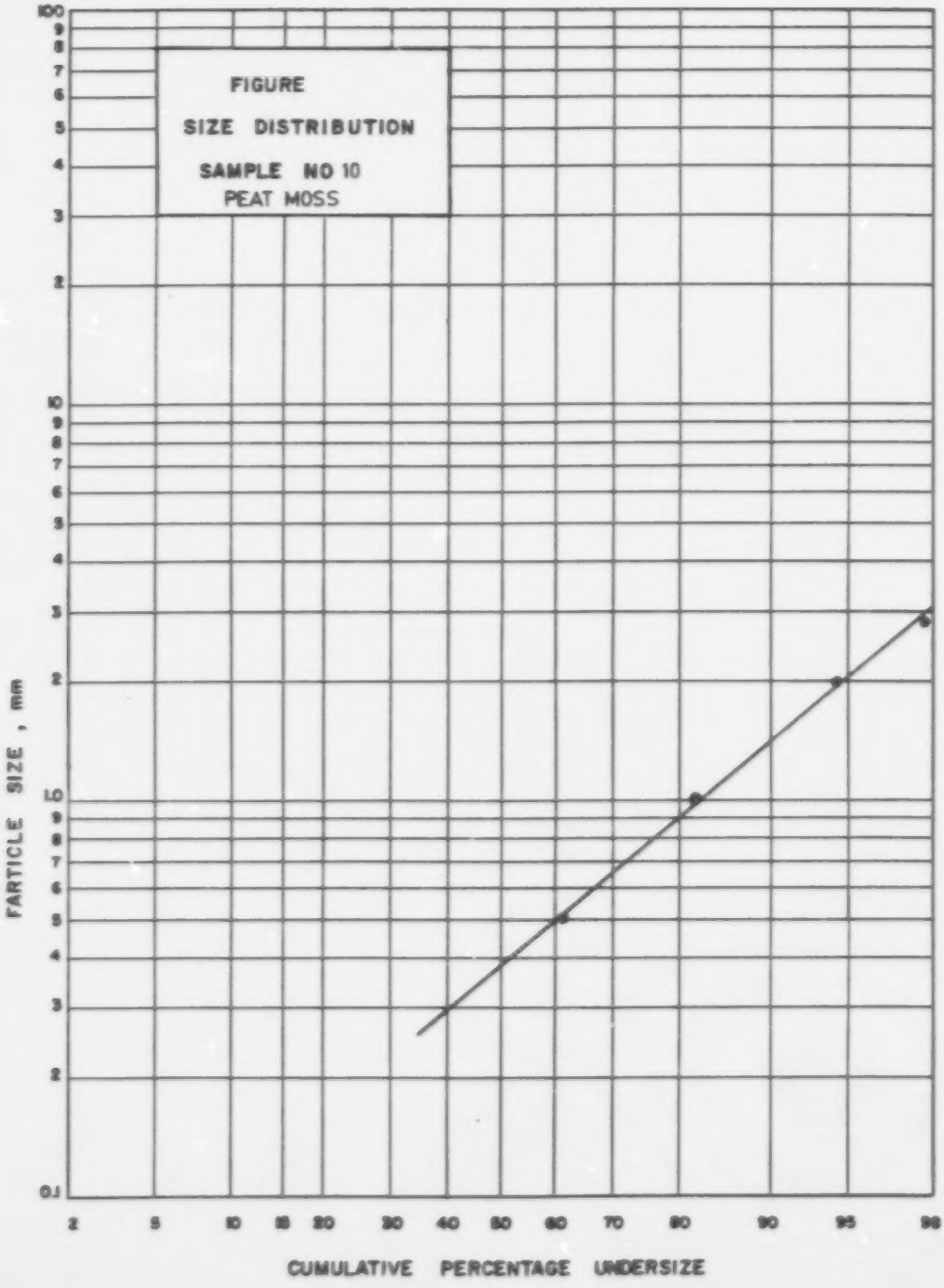


Table A27. Flow Properties - Perlite Ore

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	14.6	34.0	14.3	2.38	52.0	50.67	2.19	.78
24.3	23.6	53.7	20.1	2.67	49.6	50.67	3.09	1.10
45.0	42.2	92.9	29.8	3.12	46.5	50.67	4.57	1.63
60.3	54.0	123.5	38.8	3.19	46.1	50.67	5.95	2.13
85.6	74.2	171.6	51.0	3.37	45.1	50.67	7.83	2.80
115.9	100.0	225.5	61.8	3.65	43.6	50.67	9.48	3.39

SHEAR INDEX (N) = 1.54

YIELD LOCUS	PERCENT FIT
1	99.3
2	99.9
3	99.4
4	99.9
5	99.7
6	99.5

A21. Material & Hopper Flow Factors - Perlite Ore

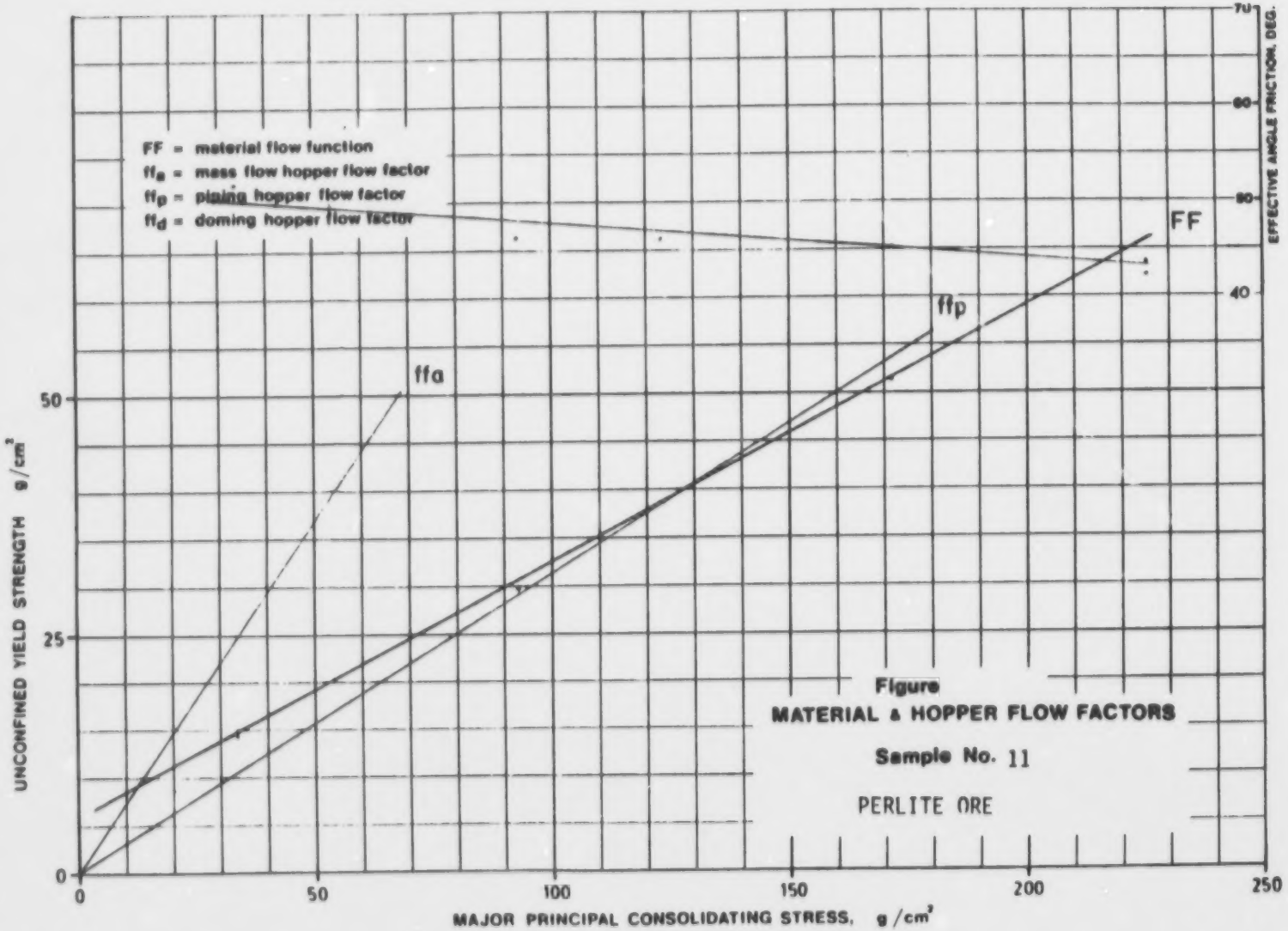


Table A28. Shear Test Results - Iron Ore

CONSOLIDATION		YIELD	
NORMAL STRESS G/SQ CM	SHEAR STRESS G/SQ CM	NORMAL STRESS G/SQ CM	SHEAR STRESS G/SQ CM
14.6	16.2		
		1.5	7.0
		2.9	8.8
		4.3	10.1
		6.2	11.0
		11.8	14.0
		13.2	14.3
		14.6	16.2
24.3	22.7		
		1.5	7.8
		2.9	9.6
		4.3	10.6
		9.0	15.6
		14.6	19.3
		21.0	22.1
		24.3	22.7
45.0	38.7		
		1.5	9.4
		2.9	11.6
		4.3	12.7
		9.0	19.7
		18.2	27.6
		33.9	34.3
		45.0	38.7
60.3	58.9		
		1.5	16.0
		2.9	16.6
		4.3	17.7
		9.0	22.6
		24.3	36.4
		45.0	51.7
		60.3	58.9
85.6	76.4		
		1.5	15.5
		4.3	17.8
		24.3	42.4
		45.0	57.4
		60.3	64.0
		70.4	68.0
		85.6	76.4
115.9	111.6		
		1.5	26.2
		4.3	25.9
		24.3	49.9
		45.0	65.2
		70.4	92.2
		85.6	99.3
		115.9	111.6

Table A29. Flow Properties - Iron Ore

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	16.2	33.9	24.3	1.40	60.1	41.96	4.29	1.32
24.3	22.7	51.2	31.7	1.62	54.1	41.96	5.60	1.73
45.0	38.7	87.7	47.1	1.86	49.1	41.96	8.32	2.57
60.3	58.9	125.0	75.1	1.66	53.0	41.96	13.28	4.09
85.6	76.4	167.6	90.9	1.84	49.5	41.96	16.07	4.95
115.9	111.6	239.8	143.8	1.67	52.9	41.96	25.41	7.83

SHEAR INDEX (N) = 1.88

YIELD LOCUS	PERCENT FIT
1	99.6
2	99.8
3	99.7
4	99.8
5	99.7
6	99.5

Figure A22. Material & Hopper Flow Factors - Iron Ore

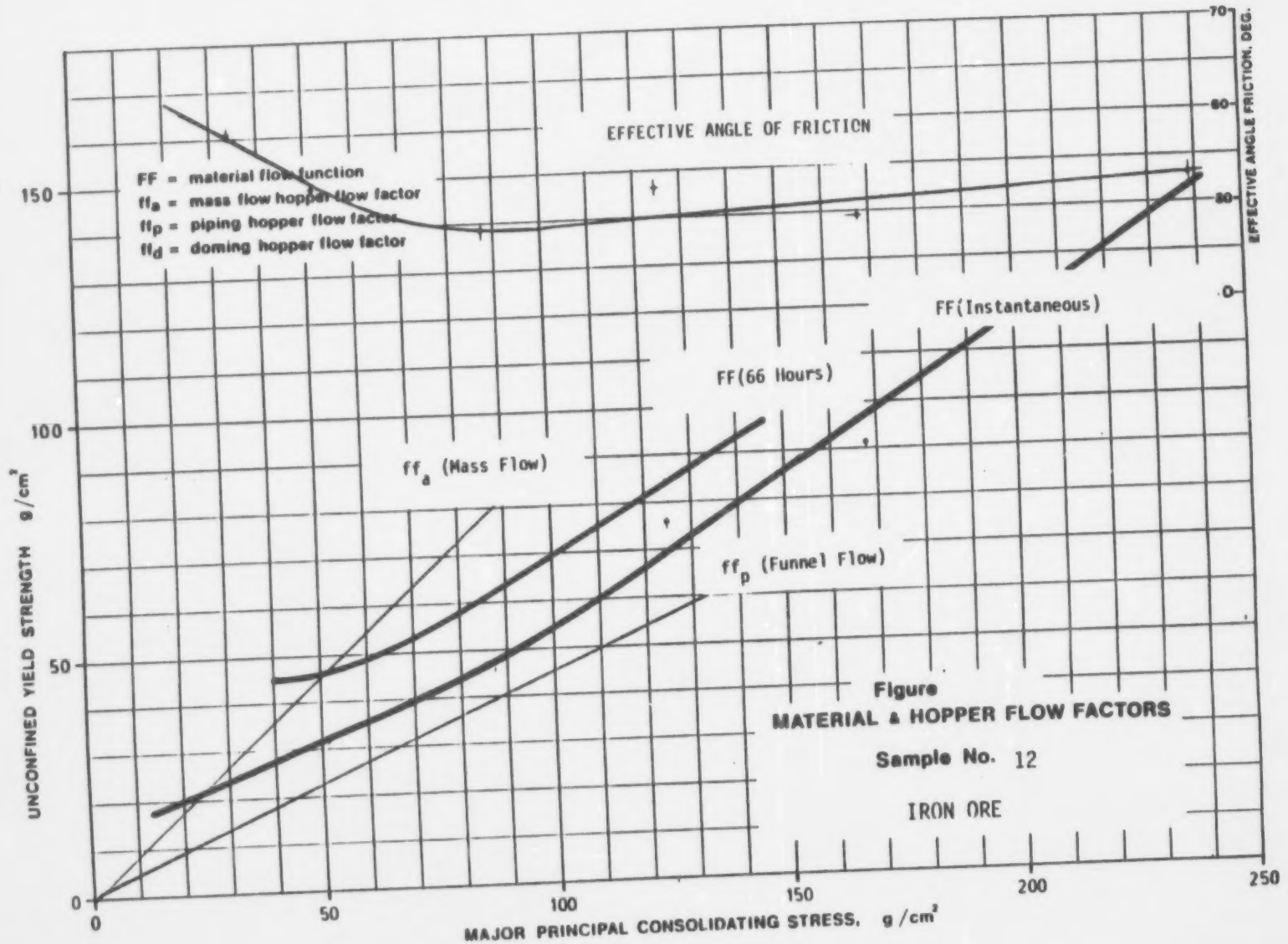


Table A30. Shear Test Results - Gold Ore

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	20.5		
		1.5	3.2
		2.9	6.9
		4.3	8.9
		6.2	9.7
		11.8	17.8
		13.2	18.5
		14.6	20.5
24.3	25.2		
		1.5	3.6
		2.9	4.3
		4.3	6.3
		9.0	10.1
		14.6	15.1
		21.0	24.7
		24.3	25.2
45.0	51.6		
		1.5	5.0
		2.9	7.0
		4.3	14.7
		9.0	19.2
		18.2	25.4
		33.9	37.6
		45.0	51.6
60.3	62.1		
		1.5	3.5
		2.9	5.1
		4.3	7.1
		9.0	13.6
		24.3	35.8
		45.0	55.3
		60.3	62.1
85.6	92.2		
		1.5	5.5
		4.3	5.9
		24.3	33.3
		45.0	60.1
		60.3	72.3
		70.4	82.7
		85.6	92.2
115.9	118.1		
		1.5	3.5
		4.3	11.9
		24.3	29.8
		45.0	44.7
		70.4	91.1
		85.6	100.9
		115.9	118.1

Table A31. Flow Properties - Gold Ore

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	20.5	49.7	13.0	3.83	57.8	60.73	1.55	.54
24.3	25.2	60.1	6.4	9.35	48.4	60.73	.77	.27
45.0	51.6	123.1	18.1	6.81	51.6	60.73	2.16	.75
60.3	62.1	156.0	19.3	8.09	49.9	60.73	2.30	.80
85.6	92.2	225.4	29.5	7.65	50.4	60.73	3.52	1.23
115.9	118.1	288.2	31.3	9.21	48.6	60.73	3.74	1.30

SHEAR INDEX (N) = 1.30

YIELD LOCUS	PERCENT FIT
1	99.7
2	99.0
3	98.7
4	99.3
5	99.7
6	98.7

Figure A23. Material & Hopper Flow Factors - Gold Ore

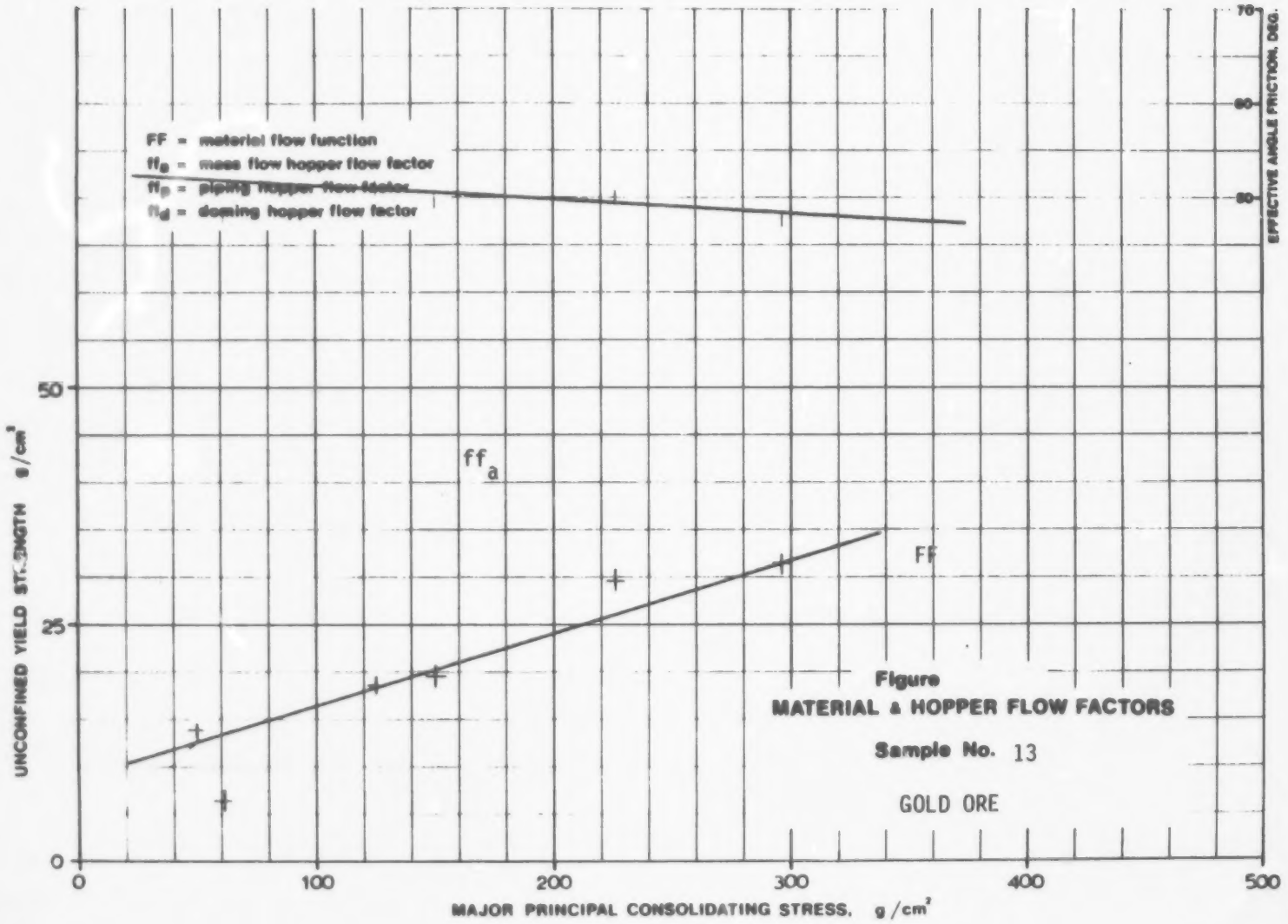


Table A32. Shear Test Results - Stringy Cedar Hogfuel

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	19.9	1.5	5.6
		2.9	6.8
		4.3	8.0
		6.2	9.3
		11.8	16.2
		13.2	18.0
		14.6	19.9
24.3	39.5	1.5	7.0
		2.9	8.7
		4.3	15.5
		9.0	24.3
		14.6	25.2
		21.0	37.1
		24.3	39.5
45.0	46.6	1.5	8.9
		2.9	11.3
		4.3	13.9
		9.0	18.1
		18.2	26.3
		33.9	38.3
		45.0	46.6
60.3	89.4	1.5	11.4
		2.9	17.8
		4.3	27.7
		9.0	32.3
		24.3	50.0
		45.0	71.2
		60.3	89.4
85.6	119.5	1.5	10.4
		4.3	23.3
		24.3	62.8
		45.0	87.8
		60.3	90.0
		70.4	100.9
		85.6	119.5

Table A33. Flow Properties - Stringy Cedar Bogfuel

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	19.9	42.3	18.4	2.30	59.0	59.98	2.02	.48
24.3	39.5	89.7	53.5	1.68	66.4	59.98	5.88	1.38
45.0	46.6	107.3	33.4	3.21	52.0	59.98	3.67	.86
60.3	89.4	202.6	108.0	1.88	63.6	59.98	11.86	2.79
85.6	119.5	269.7	132.1	2.04	61.7	59.98	14.52	3.41

SHEAR INDEX (N) = 1.56

YIELD LOCUS	PERCENT FIT
1	99.3
2	98.7
3	99.6
4	99.5
5	99.3

Figure A24. Material & Hopper Flow Factors - Stringy Cedar Hogfuel

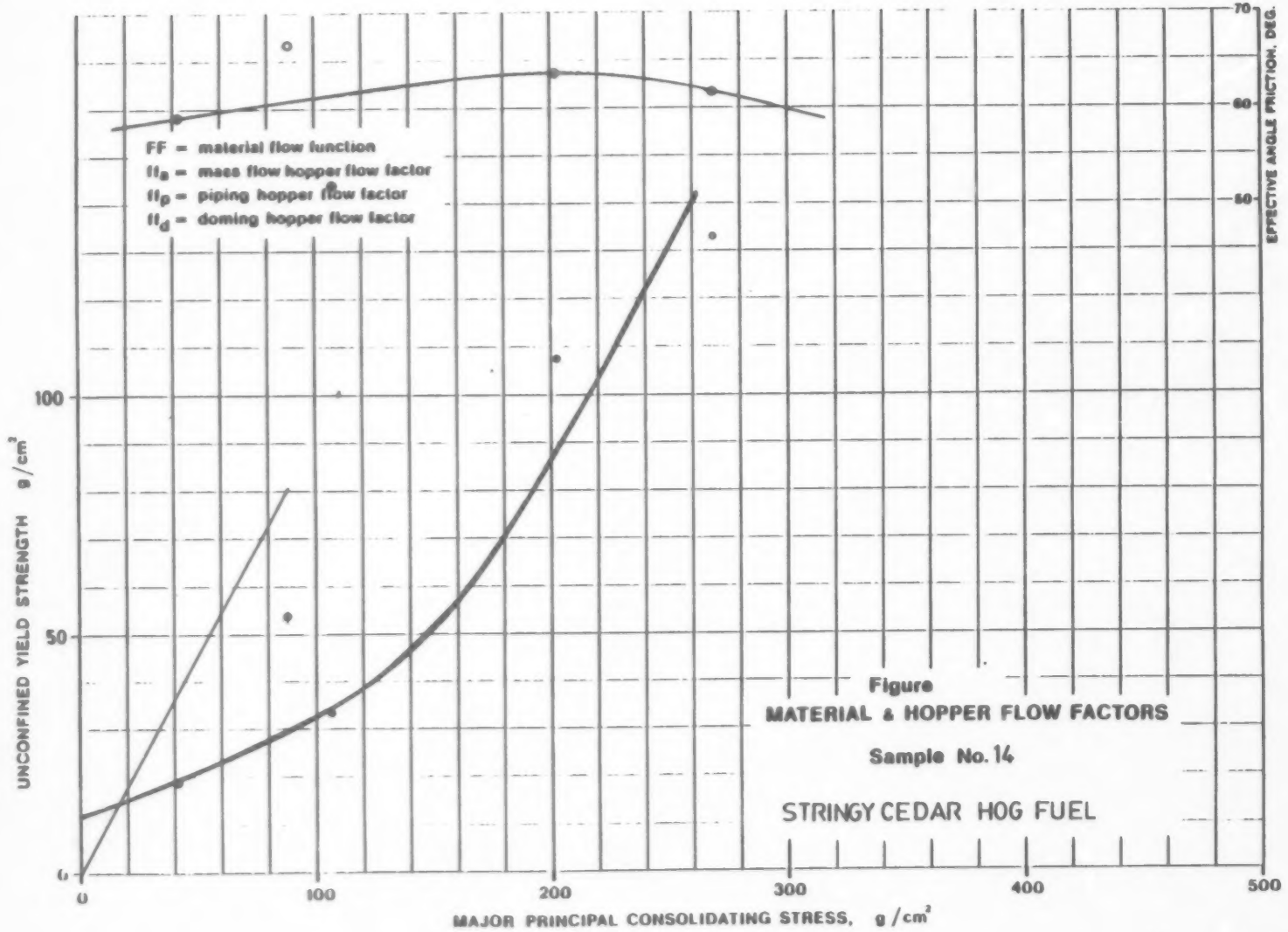


Figure A25. Particle Size Distribution - Stringy Cedar Hogfuel

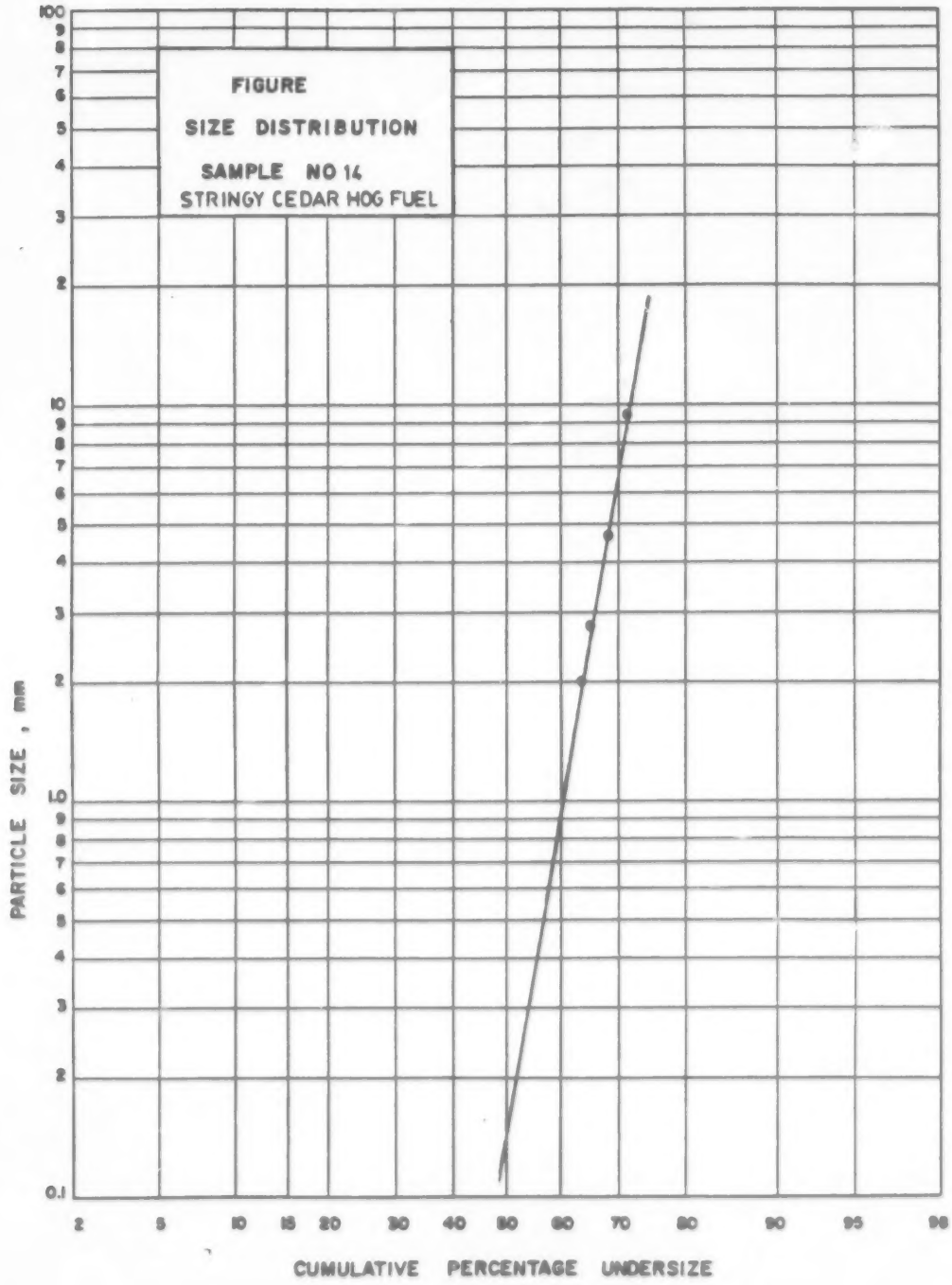


Table A34. Shear Test Results - Hemlock Hogfuel

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	19.8		
		1.5	3.1
		2.9	4.3
		4.3	6.4
		6.2	8.9
		11.8	16.1
		13.2	18.9
		14.6	19.8
24.3	25.9		
		1.5	3.3
		2.9	5.8
		4.3	7.5
		9.0	9.7
		14.6	18.9
		21.0	23.7
		24.3	25.9
24.3	25.9		
		1.5	4.1
		2.9	6.8
		4.3	7.5
		9.0	9.7
		14.6	18.9
		21.0	23.7
		24.3	25.9
60.3	74.4		
		1.5	9.1
		2.9	13.1
		4.3	21.6
		9.0	20.2
		24.3	33.7
		45.0	61.5
		60.3	74.4
85.6	108.8		
		1.5	5.0
		4.3	16.1
		24.3	49.4
		45.0	75.7
		60.3	81.6
		70.4	97.9
		85.6	108.8

Table A35. Flow Properties - Hemlock Bogfuel

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	19.8	45.3	10.5	4.30	56.0	61.44	1.21	.39
24.3	25.9	61.7	8.5	7.26	49.9	61.44	.98	.31
24.3	25.9	62.1	8.7	7.14	50.1	61.44	1.00	.32
60.3	74.4	181.4	39.2	4.63	55.1	61.44	4.50	1.44
85.6	108.8	268.3	63.8	4.21	56.3	61.44	7.33	2.34

SHEAR INDEX (N) = 1.33

YIELD LOCUS	PERCENT FIT
1	98.8
2	99.3
3	99.2
4	98.6
5	99.6

Table A36. Time Consolidation Results - Hemlock Hogfuel

CONSOLIDATION YIELD POINT		<----------FLOW PROPERTIES---------->						
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS INST	MAJ PRINC CONSOL'N STRESS TIME	UNCONFIN YIELD STRESS	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		G/SQ CM	DEG	DEG	G/SQ CM
CONSOLIDATION PERIOD 1 HR									
14.6	15.0	14.6	17.0	45.7	40.8	6.6	52.8	61.7	.76
CONSOLIDATION PERIOD 2 HRS									
85.6	98.8	85.6	106.7	270.8	256.6	50.7	55.0	61.7	5.79
CONSOLIDATION PERIOD 16 HRS									
45.0	48.7	45.0	51.2	121.8	122.7	18.7	52.0	61.7	2.13
CONSOLIDATION PERIOD 23 HRS									
85.6	115.9	85.6	120.0	270.8	292.0	79.2	58.9	61.7	9.05

SHEAR INDEX (N) = 1.32

COHESION/ TENSILE STRENGTH = 3.10

Figure A26. Material & Hopper Flow Factors - Hemlock Hogfuel

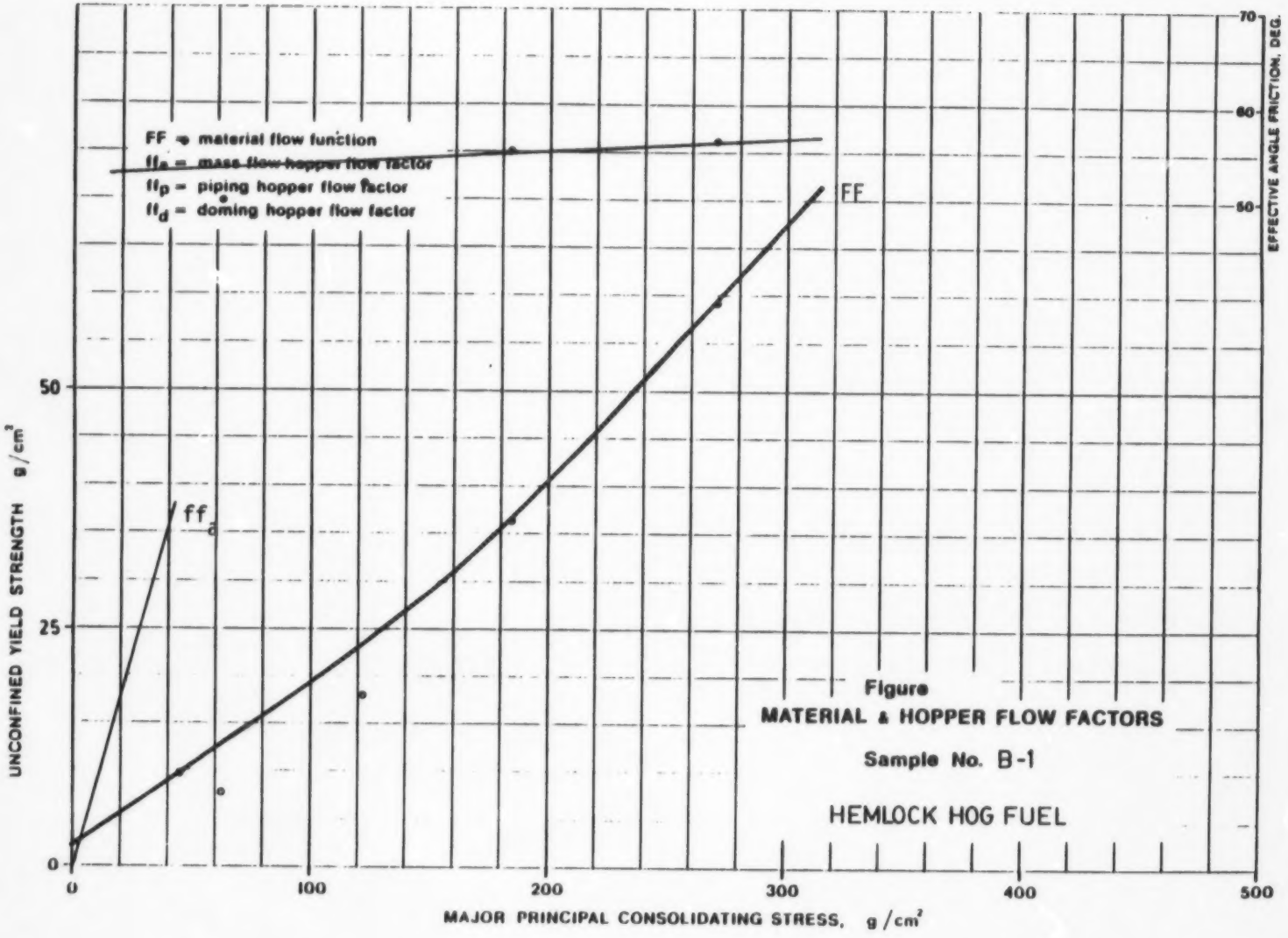


Table A37. Shear Test Results - Hemlock Sawdust

CONSOLIDATION		YIELD	
NORMAL STRESS	SHEAR STRESS	NORMAL STRESS	SHEAR STRESS
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM
14.6	19.4		
		1.5	3.8
		2.9	5.5
		4.3	7.3
		6.2	12.2
		11.8	15.8
		13.2	18.8
		14.6	19.4
24.3	27.0		
		1.5	3.6
		2.9	4.9
		4.3	6.6
		9.0	12.7
		14.6	19.1
		21.0	23.4
		24.3	27.0
45.0	55.9		
		1.5	5.4
		2.9	6.0
		4.3	12.9
		9.0	19.5
		18.2	30.4
		33.9	42.4
		45.0	55.9
60.3	66.9		
		1.5	4.3
		2.9	5.2
		4.3	8.9
		9.0	17.0
		24.3	32.0
		45.0	52.5
		60.3	66.9
85.6	89.0		
		1.5	4.0
		4.3	7.8
		24.3	36.1
		45.0	60.6
		60.3	73.9
		70.4	84.4
		85.6	89.0

Table A38. Flow Properties - Hemlock Sawdust

CONSOLIDATION				FLOW PROPERTIES				
NORMAL STRESS	SHEAR STRESS	MAJ PRINC CONSOL'N STRESS	UNCONFIN YIELD STRESS	FLOW FUNC	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION	TENSILE STRENGTH
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		DEG	DEG	G/SQ CM	G/SQ CM
14.6	19.4	47.4	11.8	4.01	57.0	61.07	1.39	.46
24.3	27.0	63.8	9.2	6.96	50.7	61.07	1.07	.36
45.0	55.9	133.5	26.8	4.98	54.4	61.07	3.14	1.04
60.3	66.9	156.7	21.9	7.17	50.4	61.07	2.56	.85
85.6	89.0	224.3	32.1	7.00	50.7	61.07	3.76	1.25

SHEAR INDEX (N) = 1.32

YIELD LOCUS	PERCENT FIT
1	99.4
2	99.8
3	99.5
4	99.8
5	99.6

Table A39. Time Consolidation Results - Hemlock Sawdust

CONSOLIDATION NORMAL STRESS	CONSOLIDATION SHEAR STRESS	YIELD POINT NORMAL STRESS	YIELD POINT SHEAR STRESS	FLOW PROPERTIES: MAJ PRINC CONSOL'N STRESS INST	MAJ PRINC CONSOL'N STRESS TIME	UNCONFIN YIELD STRESS	EFFECT FRIC ANGLE	INTERNAL FRIC ANG AT FREE SURFACE	COHESION
G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM	G/SQ CM		G/SQ CM	DEG	DEG	G/SQ CM
CONSOLIDATION PERIOD 5 HRS									
85.6	89.7	85.6	99.3	224.4	237.8	40.4	52.7	61.1	4.72
CONSOLIDATION PERIOD 17 HRS									
24.3	29.2	24.3	30.3	63.9	72.8	15.2	55.0	61.1	1.77
45.0	48.6	45.0	51.7	133.7	123.8	20.4	52.4	61.1	2.39
CONSOLIDATION PERIOD 65 HRS									
45.0	51.7	45.0	55.6	133.7	133.5	27.1	54.7	61.1	3.17

SHEAR INDEX (N) = 1.32

COHESION/ TENSILE STRENGTH = 3.02

Figure A27. Material & Hopper Flow Factors - Hemlock Sawdust